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AN EXPERIMENTAL EVALUATION OF SELECTED REWARMING THERAPIES FOR --ETC(U)
AUG 79 R M HARNETT , E M O'BRIEN , F R SIAS DOT-CG-72074-A

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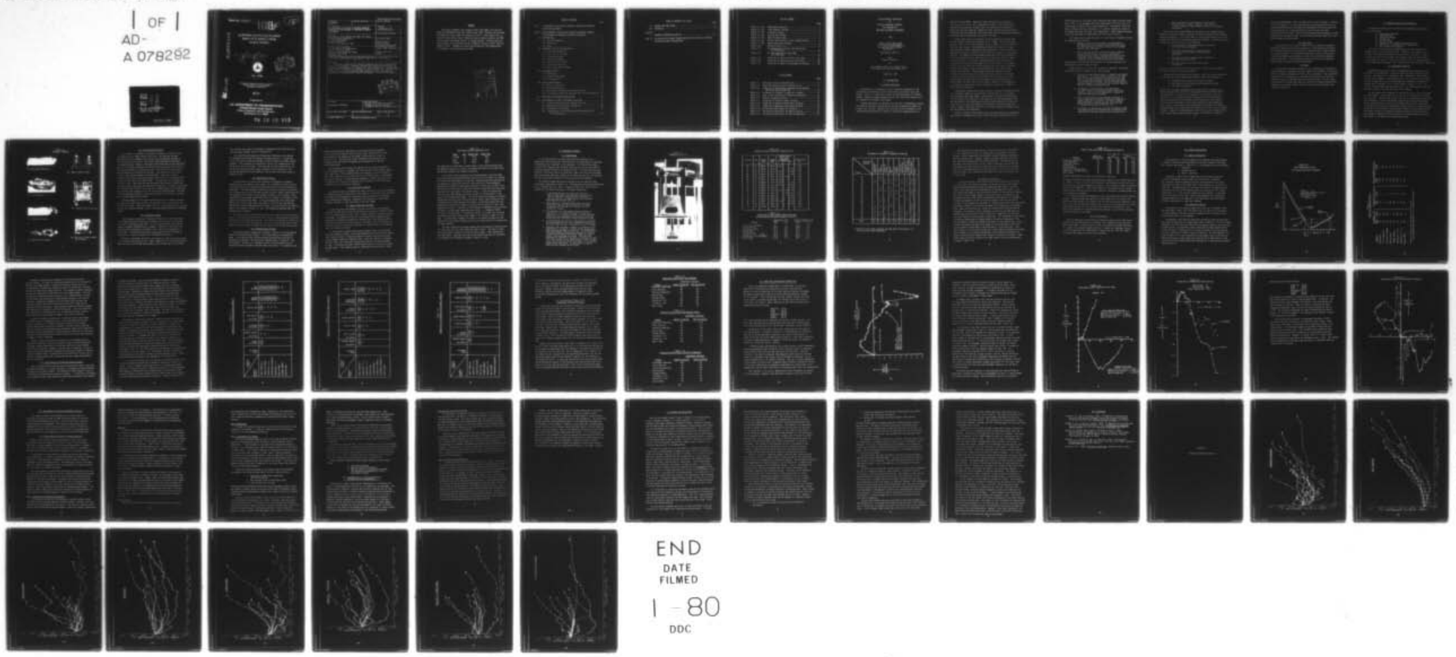

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Report No. CG-D-65-79 -PT-2

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(6) AN EXPERIMENTAL EVALUATION OF SELECTED REWARMING THERAPIES FOR THE TREATMENT OF PROFOUND ACCIDENTAL HYPOTHERMIA.

Part II.

(10) R. Michael/Harnett, Edward M./O'Brien,
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(9) FINAL REPORT. 5 Jun 78-30 Jun 79 on Phase 3,

Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151

(11) 27 Aug 79

JUNE 1979 (12) 60

Prepared for (15) DOT-CG-72074-A

U.S. DEPARTMENT OF TRANSPORTATION
United States Coast Guard
Office of Research and Development
Washington, D.C. 20590

79 12 13 015

408 039

Technical Report Documentation Page

1. Report No.
CG-D-65-79

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
AN EXPERIMENTAL EVALUATION OF SELECTED REWARMING THERAPIES FOR THE TREATMENT OF PROFOUND ACCIDENTAL HYPOTHERMIA.

5. Report Date
August 27, 1979

6. Performing Organization Code

7. Author(s)
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8. Performing Organization Report No.

9. Performing Organization Name and Address
College of Engineering
Clemson University
Clemson, South Carolina 29631

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
DOT-CG-72074-A

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
United States Coast Guard
Office of Research and Development
Washington, DC 20590

13. Type of Report and Period Covered
Final Report, Part II
June 5, 1978 to June 30, 1979

14. Sponsoring Agency Code
G-DSA

15. Supplementary Notes
This report summarizes work performed under Task Number 3 of subject contract and was technically monitored by LT$_{jg}$ Steven F. Wiker and Ens John A. Budde.

16. Abstract
This report summarizes the results of rewarming experiments performed with mildly cooled volunteers. Rewarming therapies are studied which can be used for treatment of hypothermia at the rescue site. Other therapies are included in the study to serve as standards of comparison for the "portable" ones. The results are analyzed in the context of expected human responses to arrive at comparative evaluations of the therapies for use in the treatment of "profound" hypothermia.

17. Key Words
Hypothermia, Rewarming

18. Distribution Statement
Document is available to the public through the National Technical Information Service, Springfield, VA 22151

19. Security Classif. (of this report)

20. Security Classif. (of this page)

21. No. of Pages

22. Price

Form DOT F 1700.7 (8-72)

PREFACE

This report documents work conducted under Task Number 3 of Contract Number DOT-CG-72074-A from June, 1978 to June, 1979. The work was performed at Clemson University under the auspices of the U.S. Coast Guard with LT$_{jg}$ Steven F. Wiker and Ens John A. Budde serving as program technical monitors. The principal investigator was Dr. R. Michael Harnett. Faculty associates participating in the research were Drs. Edward M. O'Brien, Fred R. Sias and James R. Pruitt. Graduate assistants participating in the research were Jim Strawhorn, Tom Horseman and Jay Smith.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF TABLES

AN EXPERIMENTAL EVALUATION
OF
SELECTED REWARMING THERAPIES
FOR TREATMENT OF
PROFOUND ACCIDENTAL HYPOTHERMIA

FOR

UNITED STATES COAST GUARD
U. S. Coast Guard Headquarters
Contract No. DOT-CG-72074-A
Task Number 3

Final Report, Part II

From
Clemson University

by

R.M. Harnett, Ph.D., E.M. O'Brien, Ph.D.,
F.R. Sias, Ph.D. and J.R. Pruitt, M.D.

August 27, 1979

1.0 INTRODUCTION

1.1 General Background

The objective in rewarming victims of immersion hypothermia is the restoration of normothermia without precipitating additional fatal side effects. Since it is known that victims of mild hypothermia will normally recover if they are simply removed from the cold, the primary concern is in the treatment of profoundly cold people.

Profound hypothermia is defined to be the level of hypothermia in which the method of treatment received by the patient can materially effect his prospects for survival. Based on the literature survey by Harnett, et al. (1979) profound hypothermia is taken to involve core temperatures at or

below 31°C (about 88°F). Above this level the patients are generally conscious and shivering, their respiratory function is not significantly depressed and myocardial irritability is not sufficiently pronounced to necessitate delicate handling. Below this level the patients are generally unconscious and not shivering, their respiratory function becomes progressively more depressed and myocardial irritability increases.

Intense debate has persisted over the best approach to treating such patients and was summarized by Harnett, et al. (1979). While the present purpose is not to reiterate the details of this debate, it will be useful to state the major points. The debate has produced two schools of thought - one supporting "rapid" rewarming by the application of "active" rewarming measures and the other supporting "slow" rewarming through a more "passive" approach. The debate has been fueled at least partially by the ambiguity of the terms rapid and slow, but there are two basically different underlying philosophies. Individuals advocating active rewarming cite the desirability of minimizing the amount of time the patient is in the hypothermic state and claim that active rewarming can, when properly applied, minimize the tendency toward afterdrop (additional core cooling after removal from the cold). The advocates of passive rewarming cite the tendency of active rewarming to produce hypotension and to restore heat to parts of the body before the distributions of electrolytes, the acid-base balance, the respiratory minute volume, and the distribution of fluids within the body return to near-normal. However, the preponderence of evidence for and against specific therapies is expressed in terms of their thermal performance.

A phenomenon termed "post-rescue collapse", in which individuals rescued from cold-water immersion die within the next half hour or so, has been well documented (Keatinge, 1969). Unfortunately, the cause of these deaths remains a matter for conjecture. For some time the leading explanation has been afterdrop in the temperature of the heart resulting from the return of relatively cold blood, associated with increased circulation through the limbs. However, relatively recent British research (Golden and Hervey, 1977) has cast doubt on this mechanism.

Golden and Hervey (1977) demonstrated that profoundly-cold, anesthetized pigs (rectal, esophageal and central venous blood mean temperatures all of

30.7°C) when put in a hot bath (41°C) exhibited some rectal afterdrop (mean about 0.4°C), less esophageal afterdrop (mean about 0.2°C) and essentially no afterdrop in central venous blood temperature. Furthermore, Golden and Hervey indicate that when rewarmed with circulation stopped (by cessation of cardiac function), the pigs' core temperatures: "again showed afterdrops with rectal and gastric temperatures lower than central venous."

This report has provided the basis for a new trend in thought which may be characterized as follows:

1. Probably too much has been made of the phenomenon of afterdrop which is so regularly observed at the rectal site but which does not occur at core sites of greater concern, e.g., the heart.

2. Since afterdrop does not require circulatory redistribution of heat to occur, it is not significantly influenced by peripheral vasodilatation during initial rewarming. Thus, attempts to heat the core without promoting peripheral vasodilatation are wasted effort.

No new trend in thought has yet come forth to replace afterdrop as an explanation for post-rescue collapse.

These views are, of course, not universally supported. Criticisms of this new trend in thought include the following.

1. The pig is a poor analog for man in regards to peripheral vasculature. It has only about 15 percent of its body mass in the limbs compared to 40 percent for man; and there are obvious differences between hoofs and highly vascularized feet and hands. The pig therefore makes a weak case against the involvement of peripheral vasodilatation in promoting afterdrop in man.

2. The amount of the afterdrops occurring without circulation were not mentioned by Golden and Hervey, therefore, they can not be meaningfully compared to those occurring with circulation.

3. The hot bath rewarming used by Golden and Hervey is widely recognized to minimize afterdrop as compared to other techniques of rewarming. Hot bath rewarming therefore makes a weak case against the occurrence of afterdrop at any particular core site.

4. It ignores the observations of Cooper and Kenyon (1957). They demonstrated the involvement of circulation in the rewarming of profoundly cooled surgical patients who,

when circulation was instantaneously restored (by removal of aortic clamps), began a slight recession in rectal temperature and a larger recession in esophageal temperature.

There is no clear understanding of the nature of the response of profoundly cold humans to removal from the cold and the application of different rewarming treatments. As a result there is no well established criterion for evaluating the merits of alternative rewarming treatments. Candidate criteria include, but are not limited to, the following.

1. The propensity to preclude afterdrop (intended to avert post-rescue collapse)
2. The rate of rewarming (with some individuals supporting slow and others supporting rapid approaches)
3. The stabilization of blood pressure (intended to preclude hypovolemic shock)
4. The prevention of significant electrolyte disturbances.

Of course, some combination of these and other criteria could be used as a basis for selecting a rewarming treatment.

Regardless of what evaluation criterion is used, the therapy evaluation must be based on the following three imperfect sources of information.

1. experiments with mildly cooled human volunteers
2. experiments with profoundly cooled laboratory animals
3. clinical observations

Experiments with human volunteers present difficulties in getting core temperature measured at the heart site because of adverse effects of the instrumentation. And even if this problem is circumvented, only mild depressions in core temperature may be induced with reasonable safety. Thus the determination of selection criteria may have to compensate for indirectness of measurement as well as the mildness of the hypothermia being treated. Experiments with animals allow the treatment of profound hypothermia and direct measurement of temperatures at core sites of greatest interest. However, the applicability to man of conclusions regarding therapeutic effectiveness based on animal studies is difficult to establish

beyond reasonable doubt. (This contrasts with the use of animals to identify "potential hazards".) Clinical observations may be obtained from cases of profound hypothermia but the temperature measurements are often superficial and are obtained in a millieu designed to save lives not to gather controlled scientific data. While clinical observations may suggest fruitful directions for systematic study, they are slow to provide a basis for evaluating therapeutic effectiveness.

1.2 Objectives

The objectives of this part of Task III were to postulate candidate methods for rewarming victims of hypothermia in the emergency environment and to design and execute an experiment to determine their effectivenesses as rescue techniques. The rewarming methods were limited to those which could be performed by an individual trained at the level of an emergency medical technician. The therapies were evaluated for their prospective effectiveness in treating profound hypothermia.

1.3 Scope

The rewarming therapies evaluated in this research were formulated to make maximum use of equipment that was commercially available. The present effort included no development of new prototype equipment. The experimental evaluation of the therapies was performed in conjunction with the cold-immersion protection equipment testing described in Part I of this report. The evaluation was based upon data which could be obtained by applying the therapies to volunteer subjects following their cooling during the cold-immersion experiments.

2.0 THERAPIES SELECTED FOR EVALUATION

The therapies selected for inclusion in the experimental evaluation are the following:

1. Spontaneous rewarming
2. Trunk immersion
3. Inhalation therapy
4. Heating pads
5. Plumbed garment
6. Combination of inhalation and heating pads
7. Combination of inhalation and plumbed garment
8. Body-to-body heat exchange

Therapies 3 through 8 were included because of their potential for effective use in the rescue environment. Therapies 1 and 2 were included for their usefulness as standards of comparison for the others. In the following sections of this chapter the conceptual basis for each therapy is discussed, the manner in which it was applied during the experimentation is described and all equipment used in administering the therapies is identified.

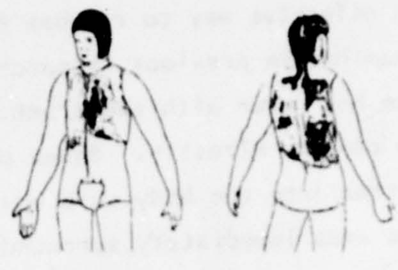
2.1 Spontaneous Rewarming

Spontaneous rewarming by shivering thermogenesis was used as a control experiment in the evaluation. No active heating of any kind was given the subjects. They were simply undressed to their undershorts, towel dried (if they were wet), placed in a reclined position on a 4 inch thick foam rubber mattress (covered by a cotton mattress pad) and immediately covered with a standard acrylic blanket. This is illustrated in Figure II-1 (a). This position and these materials were used in all "dry" rewarmings with only the exceptions cited in the later sections of this chapter.

Two approaches were considered for determining when to cover the subject with the blanket. The simplest was to cover him at the beginning of the rewarming period. The other was to cover him when his average skin temperature had spontaneously risen to the ambient temperature of the experiment area. Because reliable monitoring of skin and ambient temperature in the rescue environment would present an operational complexity and since afterdrop could potentially be minimized by insulating the surface of the cold body from an environment perhaps warm enough to promote peripheral circulation but not warm enough to produce significant warming, the simple approach of covering the subject at the beginning of rewarming was used.

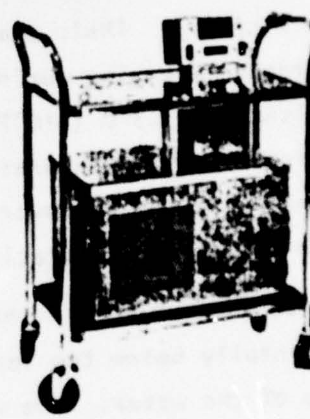
FIGURE II-1
REWARMING THERAPIES

(a) Spontaneous Rewarming



(e) Basic Plumbed Garment

(b) Trunk Immersion



(f) Thermal Conditioning Cart

(c) Inhalation Therapy

(g) Position for Body-to-Body Heat Exchange

(d) Heating Pad Placement

2.2 Trunk Immersion Therapy

The immersion of the body in hot water is generally recognized to be an effective way to restore heat to the core. The technique has been examined in previous research with various parts of the body immersed in the hot water with the trunk. The results have varied and are difficult to compare directly. Based on the simple notion that heat can be effectively gotten into the body core while minimizing afterdrop by applying the heat to the area immediately surrounding the core, it was decided to apply the hot bath therapy only to the trunk of the body. The subjects were not dried following the immersion phase of the experiment. They were lifted by members of the research team and placed on their backs in a "claw foot" bath tub half filled with 32.2°C (90°F) water. This position is illustrated in Figure II-I (b). Their arms and legs were kept from coming in contact with the water at any time during the experimental rewarming. The water temperature was raised to 43.3°C (110°F) over a period of approximately 5 minutes and was maintained at this temperature for the duration of the experiment. The water level was adjusted to cover the chest and the water was continually agitated to eliminate thermal stratification.

With the subject in this quasi-reclined position his breathing passages were generally below the top of the tub and were a short distance above the surface of the water. One would expect that this would serendipitously provide, during trunk immersion therapy, some of the heat balance benefits of inhalation therapy.

2.3 Inhalation Therapy

The therapeutic objective of inhalation therapy is to terminate respiratory heat loss and to promote heat uptake by the tissues of the lung and the blood circulating through them. This is accomplished by providing the patient a warmed, humidified gas to breathe. Some heat is carried by the molecules of gas and some is released in the lungs by the condensation of water vapor. Inhalation therapy was conceived to permit the treatment of hypothermia in remote locations and in unfavorable conditions.

There is considerable latitude in the choice of a gas mixture to be used in the therapy (see Harnett,et al., 1979). Because the thrust of these experiments was toward the thermal performance of each therapy and mildly cooled

test subjects were used, the therapeutic advantage of most mixtures (e.g., varying oxygen content) would be imperceptible.

For experimental purposes the therapy was formulated to use ambient air heated and humidified by a Bennett Cascade Humidifier. An open loop circuit was used to avoid the problems of sterilization of a carbon dioxide absorber. The thermostat was adjusted to maintain the temperature of the gas at 42 to 44°C in the mask. This required continual monitoring of the gas temperature and periodic manual adjustment of the thermostat. The therapy was applied with the subjects in the standard position as shown in Figure II-1 (c).

2.4 Heating Pads Therapy

If one accepts the notion that afterdrop is promoted by peripheral vasodilatation, the question then arises: "Is it possible to rewarm the core by applying heat only to selected surface areas and thereby avoid promoting afterdrop?". The heating pads therapy was formulated to answer this question. The surface areas to which the heat was applied (neck, lateral thorax and groin) were selected on the basis of thermographs by Hayward, et al.,(1973). They revealed that these areas radiate heat from cold subjects (15 minutes in 7.5°C water) at relatively high rates. It was postulated that since these areas mediate high rates of heat loss, they might, with sufficient heat applied, mediate high rates of heat uptake by the core. The positioning of the heating pads is illustrated in Figure II-1 (d). The therapy was applied under the standard acrylic blanket.

The heating pads utilized were 55 watt electric pads with a three-position control. They were operated on the "high" setting. Heating pad/skin interface temperatures around 44°C were achieved. The pads were preheated to thermal equilibrium prior to initiating rewarming. Terry cloth swatches moistened in warm water were placed between the pads and the subject to facilitate heat transfer.

2.5 Plumbed Garment Therapy

The plumbed garment therapy was conceived to perform in the same general manner as the heating pads therapy -- by surface heating of selected body areas. It was desired that the device tested be essentially one that is commercially available. The cap and vest garment shown in Figure II-1 (e) was selected. The device is marketed as shown by the Aerotherm Group of Acurex Corporation located in Mountain View, California. For purposes of the

research the garment was modified to include two additional bladders which could be positioned to warm the groin area. Pressurized hot water was supplied to the garment by the termal conditioning cart shown in Figure II-1(f). The cart (part number 245-30013A) was operated at the temperature setting (114°F) indicated by the manufacturer to be the maximum safe level.

The plumbed garment therapy was applied with the subjects generally in the standard position. However, the subjects were rolled slightly toward their right side. This was determined to be necessary to avoid kinking of soft rubber connectors on the lines carrying the heated water to the garment and back to the cart. The garment was preheated to thermal equilibrium and its surfaces which contact the subjects were moistened, to facilitate heat transfers, prior to initiating rewarming.

2.6 Combination Therapies

Two therapies were considered which were formulated as simple combinations of therapies previously described in this chapter. A combination of inhalation and heating pads therapies was studied as was a combination of inhalation and plumbed garment therapies. Because of the simple way in which these therapies combined, no additional descriptions are needed.

2.7 Body-to-Body Heat Exchange

It has often been recommended in popular publications that emergency treatment of hypothermia should be performed by placing a normothermic individual in a sleeping bag with the victim if better methods of treatment cannot be applied. The potential exists for the moderate surface heating contributed by the normothermic companion to promote significant afterdrop while contributing little to the restoration of core heat. No objective data has existed to support or refute the treatment of hypothermia by the exchange of heat from one body to another.

In formulating the body-to-body heat exchange therapy it was decided that the therapeutic effect to be investigated would be restricted to simple heat transfer without introducing effects of arousal resulting from close contact between members of opposite sexes. Since the immersion volunteers were all males, only males were used as heat donors in the heat exchange therapy. To achieve procedural simplifications three of the authors served as heat donors. Their general physical characteristics are shown in Table II-1.

TABLE II-1
HEAT DONOR PHYSICAL CHARACTERISTICS

Donor	Age	Height (cm)	Weight (kg)
O'Brien	29	170.0	65.8
Sias	47	177.8	79.4
Harnett	34	182.9	86.3

The selection of a heat donor to participate in each rewarming experiment was generally made so as to match the heights and weights of the heat donor and the heat recipient as closely as possible.

It was decided that volunteers would be positioned to maximize upper body contact and that peripheral body contact would be avoided in an attempt to minimize the promulgation of afterdrop. Because localized vasodilatation in response to contact with the heat donor would facilitate subsequent heating of the subject's blood (and presumably his body core as well) it was decided that the entirety of rewarming would be accomplished with heat being applied to the same area of the subject's body. It was anticipated that there would be some surface cooling of the part of the heat donor's body contacting the rewarming subject. This would reduce the temperature gradient between heat donor and heat recipient and the rate of heat transfer as well. To determine the significance of this effect, a preliminary experiment was conducted with the donor's chest in contact with the recipient's back (both wearing only shorts). The donor's chest (pectoral) temperature was monitored. The donor's initial chest temperature was 33.2°C. It dropped to 30.8°C 4 minutes into rewarming. It recovered to 32.9°C 10 minutes into rewarming re-establishing much of the initial capacity of the donor's chest to yield heat. This experiment revealed that there is no compelling reason for the heat donor to continually change the area of his body which is in contact with the heat recipient.

The body-to-body heat exchange therapy was formulated with the donor and recipient lying on their left sides and clad in shorts. The donor's chest and stomach were in contact with the recipient's back. Their extremities were kept apart. They were reclined on the standard mattress and covered by the standard acrylic blanket as shown in Figure II-1 (g).

3.0 EXPERIMENT PROTOCOL

3.1 Methodology

It was recognized at the outset that physical exertion by the subjects during the transition from floating in the cold water to rewarming could affect their responses to the therapies. To minimize this effect a "chair lift" apparatus was installed (see Figure II-2) to permit effortless entering and exiting of the immersion tank. To further stabilize the subjects' condition during this transition, their cold-protection equipment and clothing were removed by members of the research team after the subjects had been instructed to stand still and relax as much as possible.

The rewarming experiments were conducted using the subjects whose morphology is described in Table II-2. The experiments were conducted between July 7, 1978 and April 27, 1979. A number of steps were taken to assure comparability of results obtained in different experiments.

1. To eliminate effects of diurnal variation the immersion experiments were generally started around 1:00 p.m. each day. There was some variation in the start times of the rewarmings but they generally began between 3:00 and 4:00 p.m.
2. Participation in immersion experiments, and hence rewarmings, required that the subjects have taken no medication or alcohol for 24 hours or food or tobacco for 2 hours.
3. The temperature in the research area was subject to some control. An attempt was made to conduct each rewarming in 21.1°C room air. Table II-3 shows the mean ambient dry bulb temperatures and relative humidities existing during the conduct of each rewarming therapy.
4. As mentioned earlier the "dry" therapies were performed while the subjects were in the standardized position on the foam rubber mattress covered by the acrylic blanket.
5. Because of the volunteer's freedom to withdraw from the experiments at any point, it could not be assumed that each would perform each therapy once. As the experiment program proceeded, subjects were assigned to therapies to maximize the useful comparisons among their experiments if they continued no further. The resulting assignment of subjects to therapies is indicated in Table II-4. The letters in the "Body-to-body" column indicate the initial of the heat donor from Table II-1 who participated in each experiment. No subject was allowed to experience any therapy more than once.

FIGURE II-2
HYDRAULIC CHAIR LIFT

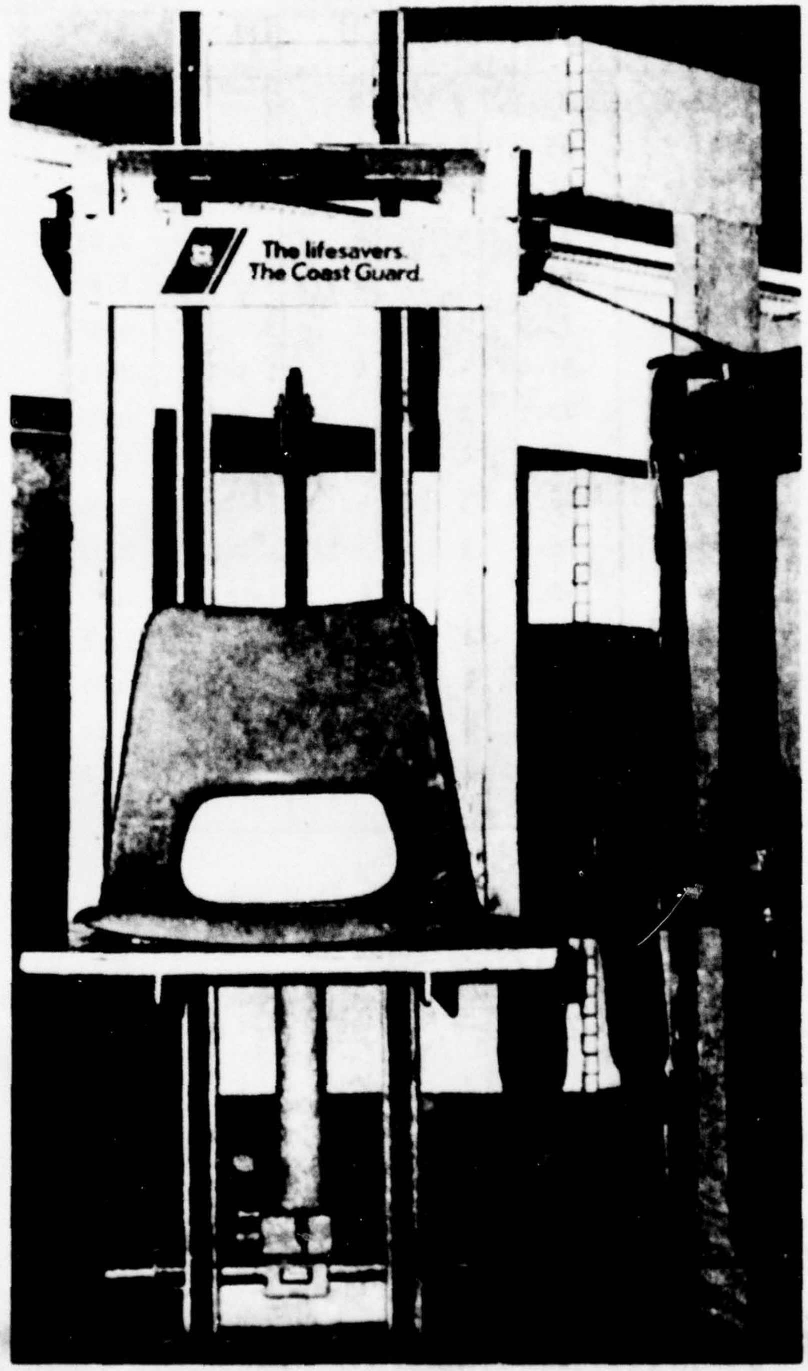


TABLE II-2
REWARMING SUBJECTS PHYSICAL CHARACTERISTICS

Subject	Age	Height (cm)	Weight (kg)	Heath-Carter Somatotype Components I	II	III	Surface Area (m^2)
KC	21	185.0	85.4	3 1/2	4	2	2.13
GE	23	182.9	65.5	2	4	4 1/2	1.86
GF	23	178.2	67.3	2 1/2	4	3 1/2	1.85
BH	23	178.9	82.7	4 1/2	4	1 1/2	2.03
MH	25	182.7	64.1	1 1/2	2 1/2	5	1.83
MK	22	183.0	75.9	2 1/2	5	3	1.98
PK	21	183.9	91.4	4 1/2	6	1 1/2	2.16
CM	21	186.6	70.2	2 1/2	3	4 1/2	1.95
RM	24	168.3	63.6	4	5	2 1/2	1.73
MO	21	180.0	76.4	3 1/2	6 1/2	2 1/2	1.96
TP	25	185.2	76.4	3	3 1/2	3 1/2	2.02
CR	19	180.4	69.3	2	4	3 1/2	1.90
JR	21	178.5	60.9	3	3	4 1/2	1.78
BS	21	187.1	71.4	2 1/2	4	4 1/2	1.96
SW	22	177.5	66.3	3	4	3 1/2	1.82
TW	22	177.0	74.5	4	4	2	1.92

TABLE II-3
COMPARISON OF MEAN AMBIENT TEMPERATURES AND
RELATIVE HUMIDITIES DURING REWARMING THERAPIES

Therapy	Temperature (°C) Mean	S.D.	Relative Humidity (%) Mean	S.D.
Spontaneous Rewarming	22.2	1.1	56.4	3.8
Trunk Immersion	22.7	2.3	59.0	4.0
Inhalation Therapy	21.1	0.6	57.7	3.4
Heating Pads	21.3	1.4	58.7	5.1
Plumbed Garment	21.2	0.2	61.3	2.6
Inhalation + Heating Pads	22.3	2.4	62.2	5.1
Inhalation + Plumbed Garment	21.3	0.8	60.6	6.2
Body-to-Body	21.8	1.4	58.1	6.6

TABLE II-4
ASSIGNMENT OF SUBJECTS TO REWARMING THERAPIES

Subject \ Rewarming Therapy	Spontaneous Rewarming	Trunk Immersion	Inhalation Therapy	Heating Pads	Plumbed Garment	Inhalation + Heating Pads	Inhalation + Plumbed Garment	Body-to-body*	Total
KC		X			X		X		3
GE	X	X	X	X	X	X	X	O	8
GF	X		X	X		X	X	O	6
BH					X		X		2
MH		X		X		X			3
MK	X	X	X	X	X	X	X	S	8
PK	X			X	X			H	4
CM				X		X			2
RM		X	X		X		X		4
MO	X	X	X						3
TP				X				S	2
CR	X	X	X	X		X		O	6
JR	X		X			X		O	4
BS	X	X			X	X	X		5
SW	X	X	X	X	X	X	X	S	8
TW	X		X			X		H	4
TOTAL	10	9	9	9	8	10	8	9	72

* Letters in this column indicate the heat donor (from Table II-1) participating in each experiment

The original experiment protocol involved monitoring on each subject six skin temperatures (great toe, thigh, groin, subscapular, bicep and forearm), rectal temperature (15 cm depth), tympanic membrane temperature, ECG and blood pressure. However, tympanic membrane temperature measurement was discontinued after only a few experiments. This was due to the discomfort and risk of injury to the tympanic membrane resulting from the impingement upon the temperature probes by various cold-protection devices worn during the immersion phase of the experiment. As a result, the estimation of body "core" temperature was based solely upon measurements made in the rectum.

3.2 Design of Experiment

It was anticipated in planning the experiment program that conducting an investigation of rewarming therapies integrated into an investigation of cold-protection devices as diverse as those described in Part I of this report could complicate the interpretation of the rewarming results. This anticipation was based on the notion that variation in the amounts of cooling and rates of cooling experienced by the subjects due to variations in the protective equipment might affect the apparent performance of the therapies. Of these two rewarming initial conditions (amount of cooling and rate of cooling) it was thought that the amount of cooling might be the more significant. Therefore, a method of controlling the design of the experiment was adopted which sought to distribute this factor as uniformly as possible across the therapies. The specific control parameter utilized was the mean amount of cooling that occurred prior to the initiation of rewarming (including the period of transition from cooling to rewarming). This parameter was controlled by adjusting assignments of cooled subjects to rewarming therapies. Thus the scheduling of rewarming therapies was done in a two-stage manner. A preliminary assignment was made on the basis of the anticipated course of the cooling phases of experiments to be performed in a given afternoon. Then when changes in this course occurred (e.g., due to early termination of cooling at the request of the subject) adjustments to the therapy assignment were made to balance the anticipated final values of the control parameter. These final values are shown, along with the mean rates of cooling preceding each therapy, in Table II-5.

TABLE II-5
MEAN INITIAL CONDITIONS FOR REWARMING THERAPIES

Therapy	Number of Replications	Prior Cooling (°C) Mean	S.D.	Rate of Cooling* (°C/hr) Mean	S.D.
Spontaneous Rewarming	10	1.44	.68	.82	0.73
Trunk Immersion	9	1.42	.42	.62	0.58
Inhalation Therapy	9	1.41	.70	.79	1.25
Heating Pads	9	1.34	.52	.81	0.96
Plumbed Garment	8	1.39	.64	.85	1.01
Inhalation + Heating Pads	10	1.43	.55	.85	1.26
Inhalation + Plumbed Garment	8	1.28	.62	.44	0.37
Body-to-Body	9	1.26	.63	.68	0.59

*Based on last 30 minutes prior to initiation of rewarming.

The mean cooling prior to each therapy exhibits a range of only 0.18°C (from 1.26 to 1.44°C). It was, of course, not possible to simultaneously control the distribution of rates of cooling among the therapies. This exhibits a range of 0.41°C/hr (from 0.44 to 0.85°C/hr). The three therapies for which mean rate of cooling is somewhat lower than the rest are trunk immersion, inhalation + plumbed garment and body-to-body heat exchange.

One final convention was adopted to censor nonrepresentative results from the analysis. Rewarming data was used from an experiment only if at least 0.5°C cooling was experienced by the subject prior to the initiation of rewarming. This level of cooling was selected, based on the results of early experiments, as being a reasonable cutoff point for evaluating the treatment of hypothermia. This restriction resulted in rewarming data being obtained in only 72 of the 90 cold-immersion experiments performed.

3.3 Instrumentation

The instrumentation used to monitor temperature data in this study was all manufactured by Yellow Springs Instruments. Skin temperatures were measured with a Model 44TD, 12-channel monitor (50°C face sweep) using Model 409 probes (1.1 second time constant) taped to the skin. Rectal and esophageal temperatures were measured with a Model 46TUC, 6-channel monitor (11°C face sweep) using Model 401 probes (7.0 second time constant).

4.0 RESULTS AND ANALYSIS

4.1 Basis of Evaluation

The evaluation of the performance of the selected rewarming therapies is based on three descriptive parameters of thermal response illustrated, for a typical experiment, in Figure II-3. The parameters are the following.

1. Afterdrop
2. Recovery period
3. Rate of rewarming

Afterdrop is taken to be the magnitude of the maximal depression in rectal temperature occurring after the initiation of rewarming. The "recovery" period is defined to be the time required for the rectal temperature to return to the level that it exhibited at the initiation of rewarming. The determination of the "rate of rewarming" is based upon the response during the first 30 minutes after the occurrence of the minimum temperature, or, if less than 30 minutes data was obtained, it was based upon the entirety of this data. These three parameters are regarded as adequately describing the response of core temperature (as approximated by rectal measurement) to rewarming treatment.

4.2 Experiment Results

The results of the rewarming experiments are given in Appendix A and are summarized in Table II-6. This table gives, for each of the three descriptive parameters, the mean value and standard error of the mean (S.E.M.) occurring with each of the therapies.

As expected, trunk immersion exhibited the smallest mean afterdrop and mean recovery period and the largest mean rate of rewarming. Of the "portable" therapies, the afterdrop occurring during spontaneous rewarming was essentially as small as any. By comparison, body-to-body heat exchange exhibited a 61 percent increase in afterdrop and a 19 percent increase in recovery period, but also a 35 percent increase in rate of rewarming. Of the 8 subjects indicated in Table II-4 to have received both spontaneous rewarming and body-to-body heat exchange, 5 experienced more afterdrop and 5 experienced a longer recovery period with body-to-body heat exchange, but 6 experienced more rapid rewarming with it.

FIGURE II-3

TIME-TEMPERATURE PROFILE:

LATE COOLING AND EARLY REWARMING

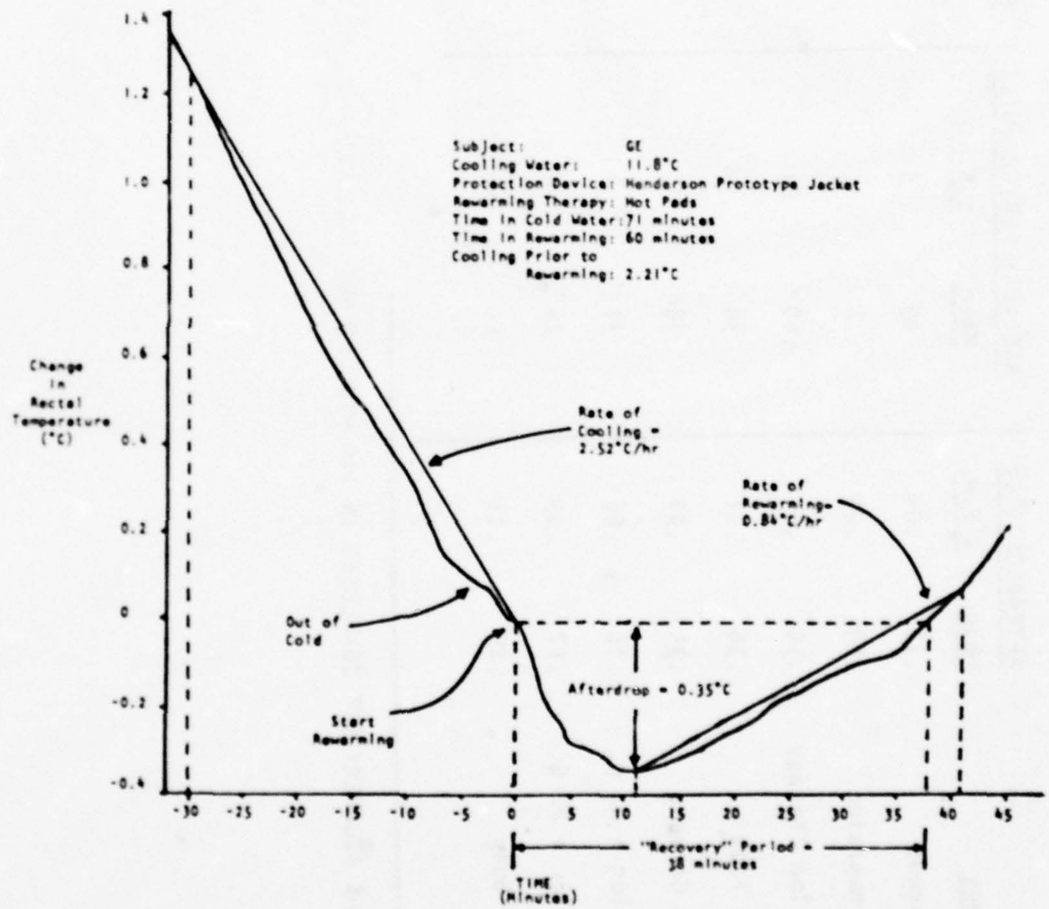


TABLE II-6

SUMMARY OF REWARMING RESULTS

Therapy	AFTERDROP (°C)		RECOVERY PERIOD (MIN)		RATE OF REWARMING (°C/hr)	
	Mean	S.E.M.	Mean	S.E.M.	Mean	S.E.M.
Spontaneous	.18	.04	43	8	0.57	.11
Trunk Immersion	.09	.03	4	1	4.47	.46
Inhalation Therapy	.16	.04	40	14	1.03	.27
Heating Pads	.36	.11	36	9	1.03	.21
Plumbed Garment	.34	.07	38*	8	0.99	.14
Inhalation + H. P.	.18	.06	31	8	0.75	.10
Inhalation + P. G.	.17	.09	26	9	1.11	.27
Body-to-Body	.29	.11	51	16	0.77	.11

*ONE RECOVERY NOT COMPLETED IN 120 MINUTES NOT INCLUDED

Inhalation rewarming also produced as little afterdrop as any portable therapy. This was not improved by augmenting it with the heating pads or the plumbed garment. Augmenting inhalation therapy with the plumbed garment shortened the recovery period by 35 percent and increased the rate of rewarming by about 8 percent. Five subjects received inhalation therapy and inhalation in combination with the plumbed garment. With the combination, 3 experienced less afterdrop, only 1 experienced an increase in the recovery period and only 2 experienced a decrease in the rate of rewarming. Augmenting inhalation with the heating pads shortened the recovery period by 10% but also exhibited a reduction in mean rate of rewarming of about 22 percent. Seven subjects received inhalation therapy and inhalation in combination with the heating pads. With the combination, only 3 experienced less afterdrop, only 3 experienced shorter recovery periods and only 3 experienced increases in the rate of rewarming.

Comparing inhalation combined with the heating pads to spontaneous rewarming, the active rewarming results in the same afterdrop as spontaneous rewarming but it affects a 28 percent reduction in the mean recovery period and a 32 percent increase in the mean rate of rewarming. Of the 7 subjects who experienced both spontaneous rewarming and inhalation combined with the heating pads, 5 experienced less afterdrop with the active rewarming, 6 experienced shorter recovery periods but only 3 experienced an increase in rate of rewarming.

Finally, comparing inhalation combined with the plumbed garment to spontaneous rewarming, the active rewarming is seen to affect essentially no change in mean afterdrop but a 40 percent reduction in mean recovery period and a 95 percent increase in the mean rate of rewarming. Of the 5 subjects who experienced both spontaneous rewarming and inhalation combined with the plumbed garment, 4 experienced less afterdrop with the active rewarming, 3 experienced shorter recovery periods and 4 experienced greater rates of rewarming.

4.3 Significance of Differences Among Therapies

Many comparisons among the therapies are possible for each of the three performance parameters. A common approach to investigating these differences is analysis of variance (ANOVA). The ANOVA would reveal whether or not any significant differences exist among the therapies. If significant differences are indicated to exist they may then be identified by applying one of several

post-ANOVA techniques. One of the requirements for ANOVA to be used is that the parameter variances within all therapies must be the same. Because of the uniformity of sample sizes, examination of the standard errors of the means given in Table II-6 indicates that this assumption is not warranted. Therefore, to assess the significance of the differences among the therapies all possible pairwise comparisons among them were examined with the Behrens-Fisher t-Test. This yields a test statistic which is known to be approximately distributed according to the Student's-t distribution and it yields an estimate of the degrees of freedom corresponding to the test statistic. These could be used to determine whether or not the differences are significant at some given level of significance. But this conveys less information than is available. The level of significance at which each difference is significant has been computed. This is often referred to as the "probability of a larger t".

The levels of significance (one-tail rejection region) are shown for comparisons in afterdrop in Table II-7, for comparisons in recovery period in Table II-8, and for comparisons in rate of rewarming in Table II-9. The appearance of a number in a cell of these tables indicates that the therapy corresponding to the cell's row is superior to the therapy corresponding to the cell's column at the level of significance given by the number in the cell. For example the .08 in the first row of Table II-7 indicates that trunk immersion is superior to inhalation therapy (with regard to afterdrop) at the .08 level of significance. This means that if the afterdrop associated with these two therapies are identical, the probability of getting the experimental results obtained with them due to randomness is .08. To find highly significant differences, one should scan these tables for small numbers. For convenience, the cells containing significance levels of about 10 percent or less have been circled. Levels above 10 percent are generally not regarded as truly significant.

It is a positive indication for a therapy to have many circles in its row and a negative indication for a therapy to have many circles in its column. Thus in regards to afterdrop, Table II-7 indicates spontaneous rewarming, inhalation rewarming, inhalation combined with the heating pads and inhalation combined with the plumbed garment to be the best of the portable therapies and heating pads and the plumbed garment are indicated to be the least attractive among the therapies. Similarly, Table II-8

TABLE II-7

COMPARISON OF AFTERDROPS AMONG THERAPIES

SUPERIOR THERAPY \ INFERIOR THERAPY	TRUNK IMMERSION	INHALATION THERAPY	INHALATION + PLUMBED GARMENT	SPONTANEOUS REWARMING	INHALATION + HEATING PADS	BODY-TO-BODY	PLUMBED GARMENT	HEATING PADS
TRUNK IMMERSION	-	.08	.20	.04	.09	.05	.01	.02
INHALATION THERAPY		-	.45	.34	.36	.13	.03	.06
INHALATION + P.G.			-	.45	.45	.19	.08	.10
SPONTANEOUS REWARMING				-	.48	.18	.05	.09
INHALATION + H.P.					-	.20	.07	.10
BODY-TO-BODY						-	.37	.33
PLUMBED GARMENT							-	.43
HEATING PADS								-

TABLE II-8

COMPARISON OF RECOVERY PERIODS AMONG THERAPIES

SUPERIOR THERAPY \ INFERIOR THERAPY	TRUNK IMMERSION	INHALATION + PLUMBED GARMENT	INHALATION + HEATING PADS	HEATING PADS	PLUMBED GARMENT	INHALATION THERAPY	SPONTANEOUS REWARMING	BODY-TO-BODY
TRUNK IMMERSION	-	.03	.00	.00	.00	.02	.00	.01
INHALATION + P.G.		-	.34	.23	.18	.21	.08	.09
INHALATION + H.P.			-	.35	.28	.29	.14	.13
HEATING PADS				-	.44	.41	.28	.20
PLUMBED GARMENT					-	.45	.31	.23
INHALATION THERAPY						-	.42	.30
SPONTANEOUS REWARMING							-	.32
BODY-TO-BODY								-

TABLE II-9

COMPARISONS OF REWARMING RATES AMONG THERAPIES

SUPERIOR THERAPY \ INFERIOR THERAPY	TRUNK IMMERSION	INHALATION + PLUMBED GARMENT	INHALATION THERAPY	HEATING PADS	PLUMBED GARMENT	INHALATION + HEATING PADS	BODY-TO-BODY	SPONTANEOUS REWARMING
TRUNK IMMERSION	-	.00	.00	.00	.00	.00	.00	.00
INHALATION + P.G.		-	.42	.41	.35	.13	.14	.05
INHALATION THERAPY			-	.50	.45	.18	.20	.08
HEATING PADS				-	.43	.12	.15	.04
PLUMBED GARMENT					-	.09	.12	.02
INHALATION + H.P.						-	.44	.13
BODY-TO-BODY							-	.11
SPONTANEOUS REWARMING								-

indicates that regarding recovery period, inhalation combined with the plumbed garment is attractive. No particular therapy of the portable ones is indicated by Table II-9 to be attractive regarding rate of rewarming. However, while the significance levels are not small, inhalation combined with the plumbed garment is superior to more of the other therapies (all but trunk immersion) than any other portable therapy.

4.4 Correlations of Results with Experiment Initial Conditions

To determine the role that variation in rewarming initial conditions (amount of cooling and rate of cooling) plays in determining the outcome of the rewarming experiments, the correlations between each of the three rewarming performance parameters and each of the initial conditions was investigated. Pearson's product-moment correlation coefficient was calculated for each combination of performance parameter and initial condition for each rewarming therapy. Table II-10 shows the correlation coefficients resulting from correlating afterdrop with each of the initial conditions. None of the r values has magnitude exceeding 0.71. Table II-11 gives the results for correlations between recovery period and each of the initial conditions. The magnitudes of these coefficients are also limited to 0.71. The correlations involving rate of rewarming, shown in Table II-12, range to larger values with 2 of them having magnitudes above 0.8.

Based on the 48 correlation coefficients in Tables II-10 through II-12, only 2 of which have magnitudes above 0.8, it is concluded that the results of the rewarming experiments were not materially influenced by variation in the rewarming initial conditions. As a consequence of this finding it is concluded that the integration of the rewarming experielements into the protection equipment tests did not materially detract from the validity of the rewarming results. It should be recalled that the rewarming experiment design balanced the amount of cooling among the therapies such that valid results could have been obtained even if this initial condition had been found to correlate reliably with one or more therapy performance parameters.

TABLE II-10

CORRELATION COEFFICIENTS FOR AFTERDROP

THERAPY	INDEPENDENT VARIABLES AMOUNT OF COOLING	RATE OF COOLING
Spontaneous Rewarming	.70	.71
Trunk Immersion	.56	.25
Inhalation Rewarming	-.22	.22
Heating Pads	.12	.44
Plumbed Garment	.16	.63
Inhalation + H.P.	.08	.27
Inhalation + P.G.	-.22	-.50
Body-to-Body	-.49	.13

TABLE II-11

CORRELATION COEFFICIENTS FOR RECOVERY PERIOD

THERAPY	INDEPENDENT VARIABLES AMOUNT OF COOLING	RATE OF COOLING
Spontaneous Rewarming	-.07	-.07
Trunk Immersion	.27	-.17
Inhalation Rewarming	-.43	-.25
Heating Pads	-.19	.23
Plumbed Garment	-.36	.10
Inhalation + H.P.	-.21	.05
Inhalation + P.G.	-.46	-.71
Body-to-Body	-.67	-.43

TABLE II-12

CORRELATION COEFFICIENTS FOR RATE OF REWARMING

THERAPY	INDEPENDENT VARIABLES AMOUNT OF COOLING	RATE OF COOLING
Spontaneous Rewarming	.08	.03
Trunk Immersion	.64	.03
Inhalation Rewarming	.92	.85
Heating Pads	.41	.42
Plumbed Garment	.59	.41
Inhalation + H.P.	.23	.01
Inhalation + P.G.	.72	.73
Body-to-Body	.37	.74

5.0 ADDITIONAL EXPERIMENTAL OBSERVATIONS

Late in the sequence of experiments, one took place in which only about 0.3°C net cooling occurred during the 3-hour cold immersion. Because this did not meet the 0.5°C minimum cooling criterion, no attempt was made to obtain data using one of the 8 rewarming therapies included in this research. Since the hot bath had been prepared and was not going to be used for a rewarming experiment, the subject was invited to sit in it to rewarm for comfort. Before entering the 35°C (95°F) water,his skin temperatures were as follows.

Great toe	16.9°C
Thigh	31.4°C
Groin	35.0°C
Subscapular	23.6°C
Bicep	29.1°C
Forearm	28.7°C

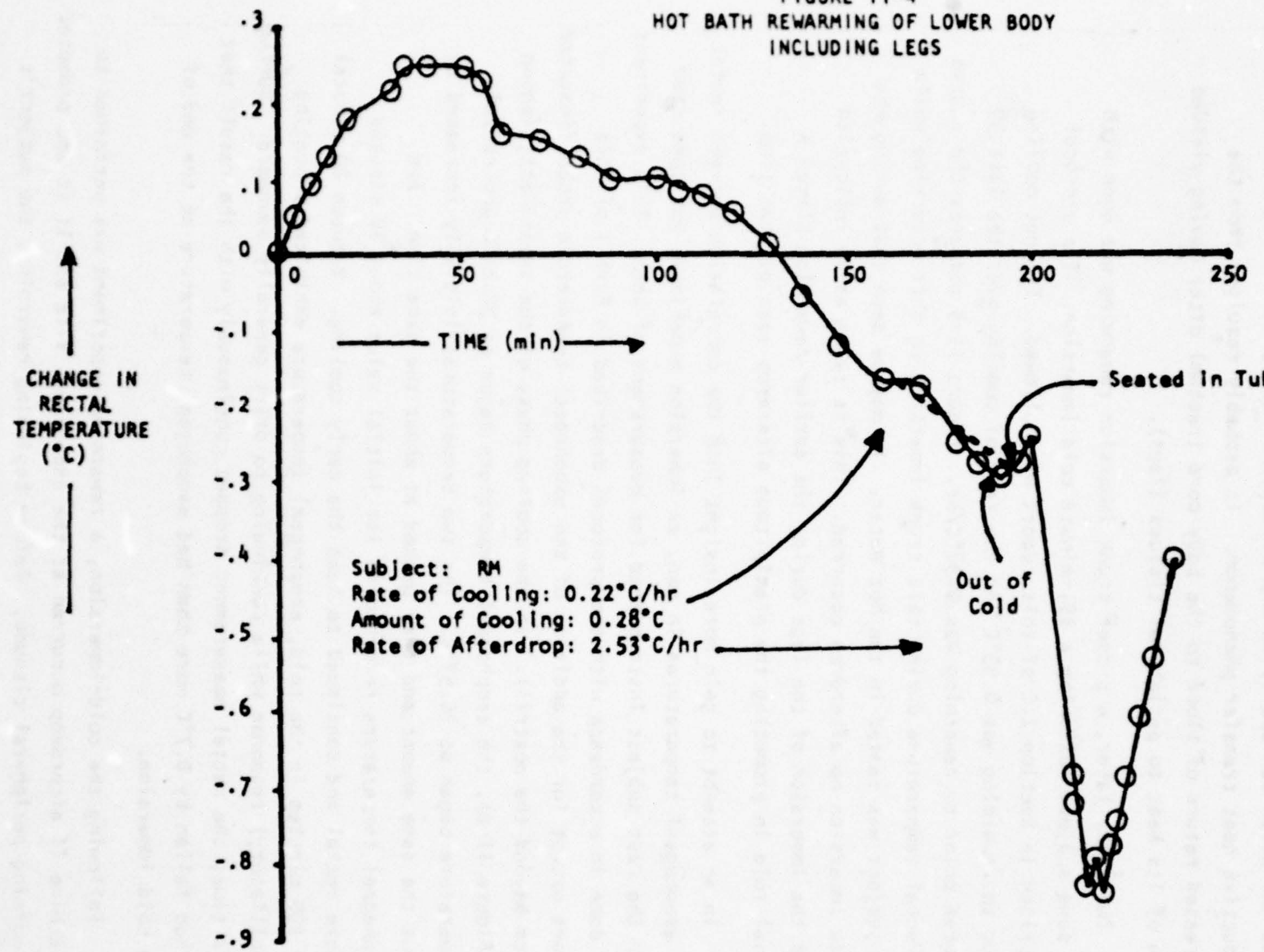
The subject entered the tub unassisted and assumed a seated position. His feet, legs and torso up to the waist level were immersed in the hot water. The surface temperatures of his toe and thigh immediately warmed to 33.0°C.

Following an initial small rise, rectal temperature fell by 0.59°C in a 14 minute period. As shown in Figure II-4, this represents an increase in the rate of rectal temperature reduction of an order of magnitude as compared to the last 30 minutes before entering the tub. After some fluctuation near the minimum temperature, a recovery of 0.44°C occurred in a 19 minute period for a rewarming rate of 1.39°C/hr.

If afterdrop was a manifestation of a conductive heat transfer phenomenon, as was suggested by Golden and Hervey (1977), one would expect to see afterdrop proceed initially at the same rate as did cooling late in the cold immersion. The rate of afterdrop, when measured rectally and with legs and lower torso immersed in warm water, should then begin to decrease in a continuous fashion until it is smoothly reversed. The rise in rectal temperature should proceed initially at an increasing rate followed by a period of slowing in the rate of warming as the temperature approaches its normal level (it is assumed that the warm water would be at a temperature near normal core temperature).

This response is, of course, idealized and normal "biological variation" is to be expected. However, the precipitous increase in the rate of rectal

FIGURE II-4
HOT BATH REWARMING OF LOWER BODY
INCLUDING LEGS



temperature reduction (while initially sitting in the hot water) as compared to the rate prevailing prior to entering the hot water, transcends one which can easily be explained as a biological variation of a conductive heat transfer phenomenon. It probably resulted from the increased return of blood to the body core (rectum) after having yielded much of its heat to peripheral tissues (legs).

Two weeks later, a proper trunk immersion rewarming was done with the same subject following a 191-minute cold immersion. The protocol described in Section 2.2 of this report was followed. The net cooling prior to rewarming was 0.93°C and the rate of cooling over the last 30 minutes prior to rewarming was 0.38°C/hr. Figure II-5 compares the course of rectal temperature during this trunk immersion to that occurring while the subject was seated in the hot water. It may be seen that during the trunk immersion no afterdrop occurred. This is taken as an indication that the immersion of the legs during the earlier rewarming played a causal role in promoting the precipitous afterdrop seen at that time.

In an attempt to gain more insight into the correlation between rectal and esophageal temperatures in man, an immersion experiment was conducted with the test subject instrumented for measurement of both. This experiment was done in accordance with the protocol described in Part I of this report except for the addition of the esophageal temperature probe (inserted 33 cm beyond the nostril). In the cooling phase of the experiment, (shown in Figure II-6), the esophageal temperature began at 36.84°C and rectal temperature began at 36.97°C. The two temperatures initially increased by about the same amount and they peaked at about the same time. But esophageal temperature returned to its initial value about 10 minutes before rectal and continued to lead the early cooling. Between 80 minutes and 190 minutes in the cold, esophageal temperature exhibited a hunting (oscillatory) response while continuing to drift generally downward. During this time, the rectal measurement dropped continuously with the result that it had fallen by 0.7°C more than had esophageal temperature at the end of the cold immersion.

Following the cold-immersion, a rewarming experiment was performed to determine if afterdrop occurred at the esophageal site and if it was promoted by warming peripheral tissues. Before beginning rewarming, the subject's

FIGURE 11-5
COMPARISON OF LEGS IN AND OUT OF HOT WATER

Subject: RM

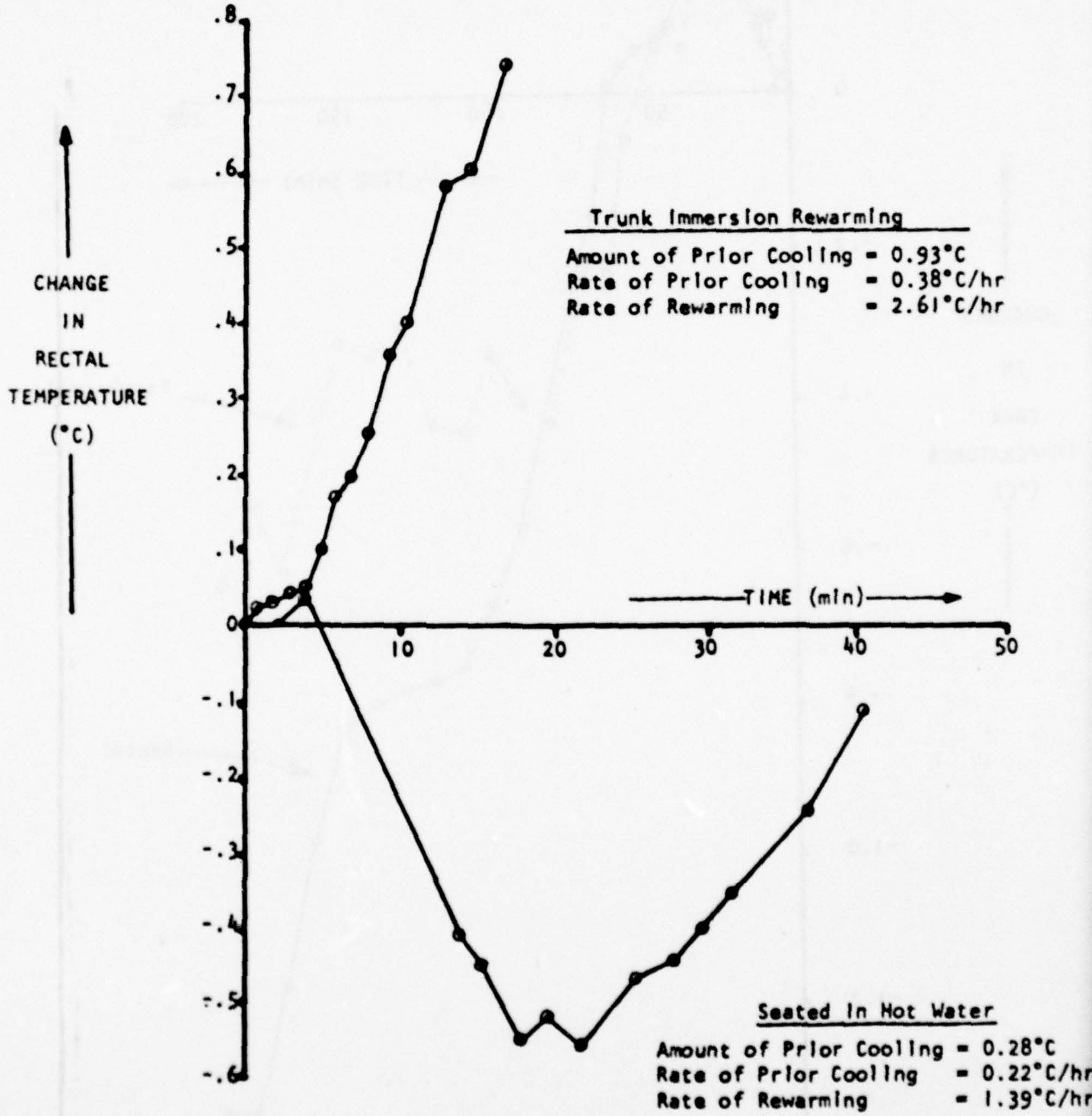
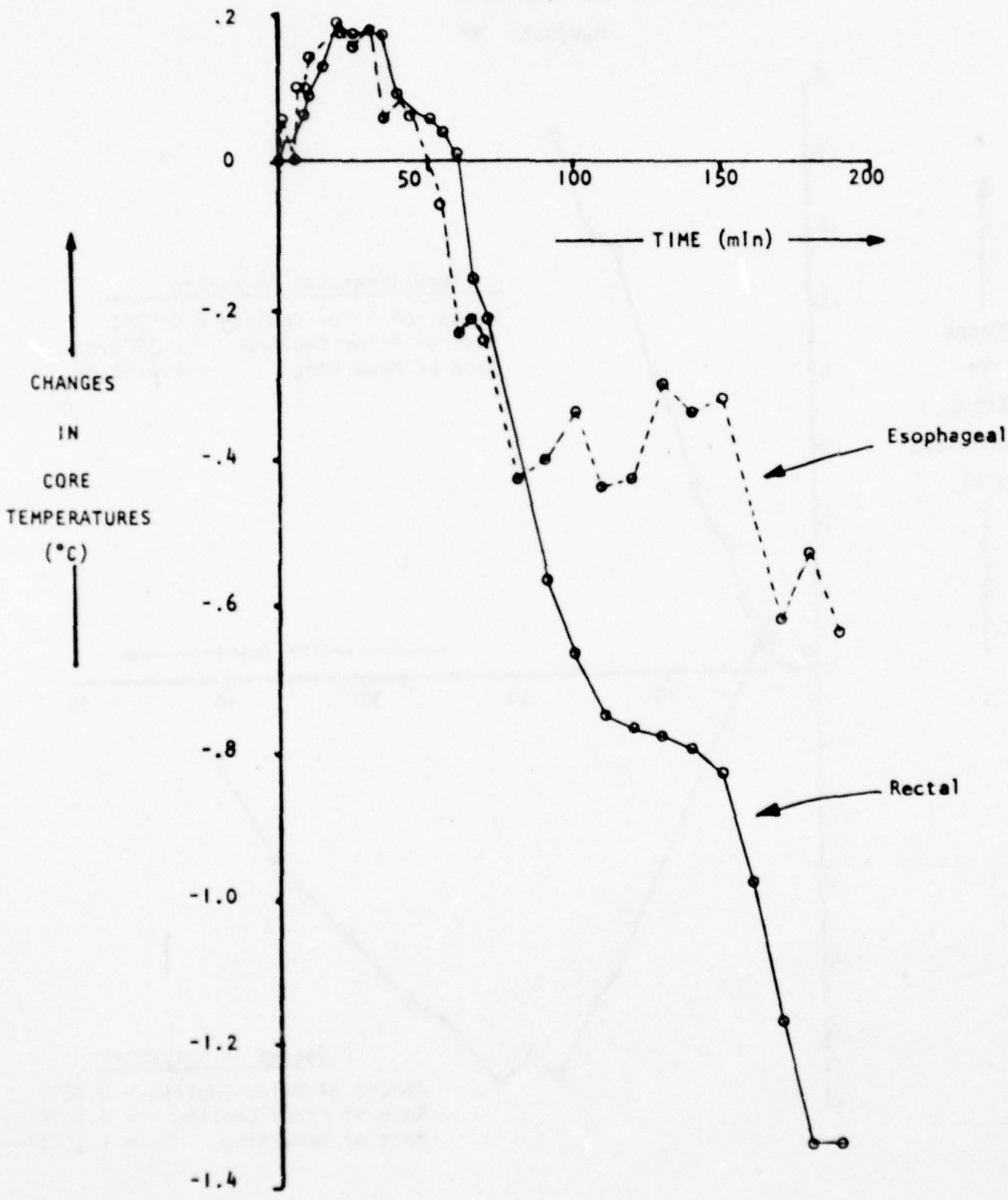


FIGURE II-6
COMPARISON OF TEMPERATURES DURING COOLING

Test Subject: TW
Test Article: DF2
Water Temperature: 1.9°C



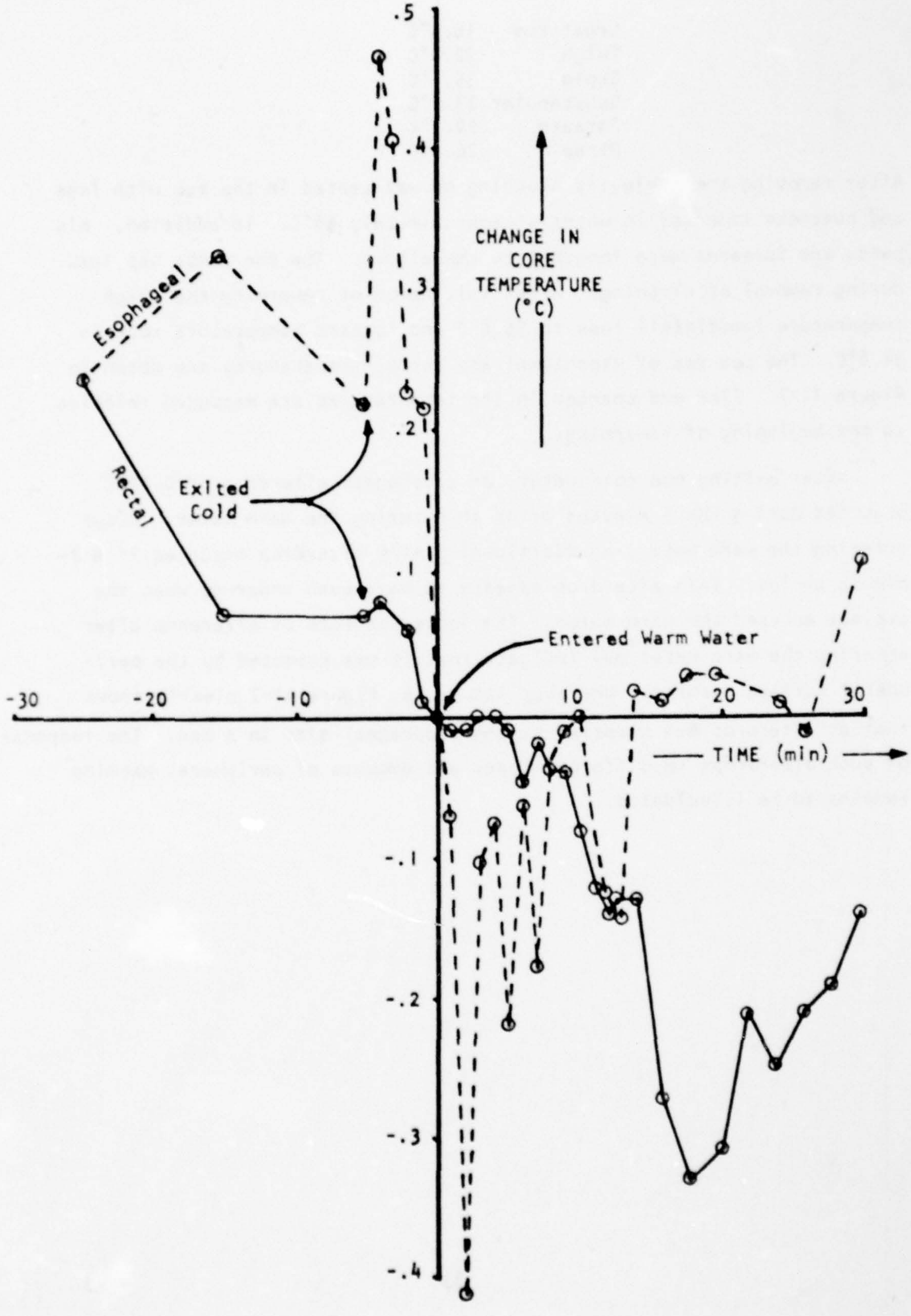
skin temperatures were as follows:

Great toe	16.5°C
Thigh	32.8°C
Groin	35.1°C
Subscapular	23.1°C
Forearm	22.1°C
Bicep	26.8°C

After removing the subject's clothing he was seated in the tub with legs and buttocks immersed in water at approximately 36°C. In addition, his hands and forearms were immersed to the elbows. The toe probe was lost during removal of clothing. After initiation of rewarming the thigh temperature immediately rose to 35.8°C and forearm temperature rose to 34.6°C. The courses of esophageal and rectal temperatures are shown in Figure II-7. Time and changes in the temperatures are measured relative to the beginning of rewarming.

After exiting the cold water, an esophageal afterdrop of 0.22°C occurred during the 5 minutes prior to entering the warm water. After entering the warm water, an additional 0.41°C afterdrop occurred in a 2-minute period. This afterdrop appears to have been underway when the subject entered the warm water. The increased rate of afterdrop after entering the warm water may indicate that it was promoted by the peripheral surface warming. Whatever its cause, Figure II-7 clearly shows that an afterdrop has occurred at the esophageal site in a man. The response of such afterdrops to different types and amounts of peripheral warming remains to be illucidated.

FIGURE II-7
COMPARISON OF RECTAL AND ESOPHAGEAL AFTERDROPS



6.0 DEVELOPMENT OF A BASIS FOR THERAPY SELECTION

This chapter presents the development of a rational basis for selecting a rewarming therapy with maximum effectiveness for treatment of profound hypothermia in the field. First, prioritized criteria for therapy selection are developed. Then special compensations are discussed which must be made in therapy selection because of fundamental differences between the conditions of the subjects of these experiments and the conditions to be expected in a victim of profound hypothermia.

6.1 Establishing Criteria for Therapy Selection

Before one can select a rewarming therapy for use in the rescue environment, one must establish a criterion or set of criteria which describes the effectiveness with which profound hypothermia is treated in the field. Establishing such criteria provides a basis for systematic evaluation of alternative therapies by helping to structure their comparison.

Formalizing the therapy selection process may also aid discussion among researchers. It clearly distinguishes between the problem of selecting criteria for the evaluation of therapies, and the problem of selecting therapies using established criteria. Thus debate may focus on the proper basis for selection separately from the interpretation of research results in the context of an established basis.

The three measures of performance (afterdrop, recovery period and rate of rewarming) used to express the results of these experiments were selected because they were felt to describe all the potentially-important thermal aspects of the rewarming process. Presumably, one should be able to describe rewarming therapeutic effectiveness in terms of these parameters and therefore, be able to define with them criteria for the selection of a therapy. (This was assumed to be so when the parameters were chosen.) The question remains, what are the relative importances of these parameters to an expression of the effectiveness of rewarming "in the field".

6.1.1 Rationale for Performance Evaluation

A distinguishing feature of the emergency treatment problem is that "non-equilibrated" patients generally must be treated. These patients still have much-restricted peripheral circulation. Such patients, when very cold, are at risk of experiencing the afterdrops in rectal and tympanic temperatures

reported frequently in the literature. Two questions must be addressed to determine the potential significance of these afterdrops. The first is, does the occurrence of these afterdrops mean that it is also occurring at the heart. The second relates to the importance of this afterdrop relative to the other thermal aspects of rewarming and will be addressed in Section 6.1.2.

Afterdrop

At the time of this writing there is divided opinion among researchers as to whether or not afterdrop occurs at the heart site when it is exhibited in a rectally-measured temperature course. Golden and Hervey (1977) raised this question, and also challenged the proposition that afterdrop is promoted by peripheral vasodilatation. It is important to recognize that their observations only raise the questions. They are far from providing definitive indications which are clearly applicable to man. No definitive answers to these questions can be drawn from the present research (although some relevant observations were presented in Chapter 5).

While there may be differences between the response of rectal temperature and those measured at more central sites, it is the authors' position that rectal data may be used as an index for comparative assessments of the propensities of various therapies to avert afterdrop which would affect much of the core. Afterdrop remains probably the best explanation for "post rescue collapse".

There is significant variability among individuals in the extent of core cooling which would be "lethal" for them. As indicated in the literature review by Harnett, et al. (1979), there is considerable evidence that the lethality of cooling can be determined only by the inability to resuscitate the victim. Whatever the level of cooling that would be lethal for a particular individual, it is probable that he could be resuscitated by simply removing him from the cold and handling him with care if he is not near his lethal level. As afterdrop in core temperature deepens, the risk increases that a lethal temperature will be encountered after treatment has begun.

Recovery Period

Recovery period relates to the amount of time the victim is in the

most-dangerously-cold temperature range. Remaining in this temperature range increases the risk that some accident while handling the victim will occur inducing afterdrop or mechanically interfering with normal cardiac function.

Rate of Rewarming

The rate of rewarming relates more to the time that the victim's core temperature is subnormal. It does not relate directly to the time the victim is in a life-threatening condition.

6.1.2 Formulation of Criteria

The three performance measures used in this research address different aspects of the rewarming process yet there is some conceptual linking among them. If the afterdrop is large then the recovery period tends to be long. If no afterdrop occurs then the recovery period is, by definition, of length zero. If the rate of rewarming is large then the recovery period tends to be short and, inversely, a small rate of rewarming generally associates with a long recovery period. Rate of rewarming is inversely related to the length of the portion of recovery period between the occurrence of the minimum temperature and the completion of recovery. The connection between afterdrop and rate of rewarming is much less direct than either of those involving recovery period.

Selecting a rewarming therapy on the basis of the three parameters considered in this study affords control of the following criteria.

1. The chance of additional, potentially lethal core cooling
2. The time the victim is particularly cold
3. The time the victim is cold

Nothwithstanding ths overlaps which tend to exist between criteria 1 and 2 and between criteria 2 and 3, we may prioritize them on the basis of their separate relative importance as threats to the lives of victims of profound hypothermia.

Criteria 2 and 3 each probably varies by only a few hours among the portable therapies considered in this study. Therefore, when one selects from these therapies he is not faced with a choice between one alternative which would involve allowing a patient to remain cold many hours longer than another alternative would. The choice could only involve allowing the patient to remain cold for a few additional hours. There is little intrinsic

danger in spending a few hours at subnormal body temperatures. (Were this not so, the technique of cryo-surgery could probably not have developed to be used as successfully as it has). Thus criterion 3 and its associated therapy performance parameter (rate of rewarming) are not of paramount importance.

Time spent in a particularly cold condition should be of much greater concern in therapy selection. During this time the victim is particularly sensitive to mishandling. Lethal interruptions of normal cardiac function, due to mechanical irritation or due to increased sensitivity resulting from afterdrop, are most likely to occur during this time. However, the condition of being particularly cold for a few hours is not in and of itself life threatening.

Afterdrop, on the other hand, is life threatening to a victim of profound hypothermia. Therefore, a rewarming therapy should be selected which minimizes afterdrop even if its selection does not minimize the recovery period (time particularly cold) and/or does not maximize the rate of rewarming (minimize time cold). It is well to remember that many researchers and clinicians favor slow rewarming for what they perceive as its own merits.

Thus a ranking of the prioritized therapy selection criteria is as follows.

1. Afterdrop avoidance
2. Recovery period minimization
3. Rate of rewarming maximization, consistent with physiologic acceptability of the associated stresses

6.2 Compensations in Interpreting Results Obtained with Mild Hypothermia

There exists a need to make certain compensations in evaluating the results of these experiments since only mild hypothermia was addressed. The subjects were all healthy, conscious and shivering vigorously at the time rewarming was initiated. Victims of profound hypothermia may be expected to exhibit reduced or extinguished shivering thermogenesis and a very much reduced respiratory minute volume (RMV). Compensations are necessary in selecting treatment methods for the differences between this laboratory condition and the real world of profoundly-cold patients. These compensations may be imperfect but they are unavoidable since rewarming-therapy research is restricted to mild hypothermia as a concession to subject safety. The primary compensations are discussed in the following paragraphs.

Reduced Respiratory Minute Volume

The reductions in a patient's RMV may be expected to reduce, more or less proportionally, the ability of inhalation therapy to introduce heat into the patient's core. This might degrade the recovery period and rate of rewarming aspects of its performance more than its afterdrop avoidance. But this is uncertain since it is not clear whether the afterdrop-avoidance property of inhalation therapy derives more from the amount of heat imparted or the *manner* in which it is imparted.

The most serious implication of the reduced RMV is the doubt it casts on the performance of the combination therapies (inhalation plus some mode of selective surface heating). As the inhalation components of the combination therapies take on diminished roles in treatment, the combination therapies begin to resemble conceptually the heating pads and plumbed garment therapies. The question is, would the combination therapies continue to perform relatively as well as they did with mildly-cooled subjects or would their relative performances more closely resemble those of the selective surface heating therapies.

Depressed Shivering Thermogenesis

In these experiments shivering thermogenesis was a major contributor to the uptake of heat involved in rewarming. There are some indications that therapies involving surface heating were negatively effected by their propensity to diminish shivering thermogenesis earlier than occurred without the surface heating. For example, of the 7 subjects who experienced both spontaneous rewarming and body-to-body heat transfer, and for whom oxygen uptake rates were measured early in rewarming (first 10 minutes), 5 subjects exhibited larger rates when rewarming spontaneously. One might expect that if no shivering had been present during <u>any</u> of these rewarmings, the opportunity would not have existed for this relative penalty to occur. The specific effects of the diminution of shivering should have included reducing the rate of rewarming and lengthening the recovery period. Therefore, in compensating for the depression of shivering thermogenesis, one would expect with surface heating, improvement in recovery period and rate of rewarming relative to those therapies involving no surface heating.

However, the primary deficiency with surface heating was in afterdrop, not recovery period or rate of rewarming. Shivering probably tends to promote afterdrop through its stimulation of blood supply to the musculature involved. Some of this musculature will be in the extremities. This shivering-induced component of afterdrop was present in the rewarmings performed with all therapies in this research. However, to the extent that surface heating reduces shivering, this component should have been smaller with the therapies involving surface heating. Even so, the therapies consisting only of surface heating exhibited the largest mean afterdrops of all. If no shivering had been present (and therefore no shivering-induced afterdrop had occurred) with any of the therapies, then the afterdrops observed with surface heating only, should have compared even less favorably to those with other therapies. There certainly is no reason to expect the absence of shivering to improve the afterdrop performance of surface heating relative to the other therapies.

7.0 SUMMARY AND CONCLUSIONS

Applying the ranked criteria listed in Chapter 6 to the experimental results presented in Chapter 4, it may be seen that of the portable therapies, spontaneous rewarming, inhalation therapy, inhalation combined with the heating pads and inhalation combined with the plumbed garment afford superior performance with respect to afterdrop avoidance. The only one of these four therapies affording a statistically-significant advantage with respect to the next most important criterion (recovery period minimization) is inhalation combined with the plumbed garment although inhalation combined with the heating pads is nearly as good. The results relating to the last criterion (rate of rewarming maximization) weakly support a selection of inhalation combined with the plumbed garment.

The question arises as to the real benefit of augmenting inhalation therapy with a plumbed garment as opposed to heating pads. Reviewing the comparisons between these two therapies in Tables II-7, II-8, and II-9, one sees that inhalation combined with the plumbed garment affords slightly smaller afterdrop and shorter recovery periods but that these differences are not significant, statistically or subjectively. The plumbed garment affords a more significant improvement in rewarming rates. It therefore seems likely that inhalation could be augmented with any selective surface heating modality to produce afterdrops and recovery periods generally similar to those seen in this study with the plumbed garment. By "selective" it is meant that the surface heating is aimed at the same general areas addressed in this study. The rate of rewarming may be subject to more control through selection of surface heating modality, since a relatively large difference was seen between the rates resulting with the two modalities used in this study when combined with inhalation therapy.

It is important to notice that the heating pads and the plumbed garment, when applied without inhalation therapy, were associated with the greatest mean afterdrops observed in these experiments. Also their recovery periods were not significantly shorter than the longest ones seen. This indicates that surface heating, even when done selectively as in this study, is not the most efficacious approach.

The combination therapies were found in these experiments to be most attractive in the context of all three performance parameters. Therefore,

one could select one of these therapies and achieve top performance in terms of afterdrop avoidance without having to make concessions in recovery period and rate of rewarming. This fortuitous result would relieve the necessity for concern over imperfections in rectal estimates of deep core temperature if consideration of the differences between mild and profound hypothermia were not necessary. The behavior of a combination therapy is unknown in treating hypothermia of various severities and with various levels of respiratory disfunction. If the relative contribution of the inhalation component diminishes as RMV decreases then the performance of the combination therapy might closely resemble that of selective surface heating alone. The corresponding changes in afterdrop avoidance would, on the basis of these experiments, deteriorate from the best to the worst achievable. The problem of choosing would not be so troublesome if the surface heating alone had not performed so poorly regarding afterdrop. Therefore, inhalation therapy alone seems to be the prudent choice for treatment when afterdrop can not be tolerated (profound hypothermia).

However, the use of inhalation therapy alone when RMV is depressed can be expected to result in reduced rates of rewarming and possibly protracted recovery periods as compared to a combination therapy. The afterdrop encountered would depend much more upon the manner in which the patient is handled than upon intrinsic aspects of the inhalation therapy. This is indicated by the similarities of the mean afterdrops observed in thses experiments with spontaneous rewarming and inhalation therapy. Therefore, while inhalation therapy alone does not increase rates of rewarming and may not reduce recovery periods (compared to spontaneous rewarming) as much as it does when combined with the plumbed garment, its use alone with very low RMV's would not promote afterdrop, as the combination therapies likely would.

Anticipating the cardiac irritability normally associated with profound hypothermia, consideration should be given to leaving such patients clothed to avoid the mechanical irritation involved in undressing them. Their surface is probably at thermal equilibrium with their wet clothing by the time they are rescued from the cold water and treatment can be initiated. However, it would be extremely important that they be wrapped in a material capable of doing the following three things.

1. Providing effective thermal insulation from the patient's environment.

2. Preventing evaporation from the wet clothing which would affect further heat drain from the patient.

3. Maintaining its thermal insulation property while exposed to water.

A normal blanket would not possess properties 2 and 3 and most sleeping bags would not. The device surrounding the patient would have to be resistent to water impinging upon it from the inside and the outside. If any of these three properties can not be satisfied, then all wet clothing should be removed. In any case, outer garments holding large quantities of water should be removed.

If *inhalation therapy* is used alone, provisions should be made for careful handling for a protracted period of time (until core rewarming is well underway). Selective surface heating could be added to the inhalation therapy once rewarming is underway and the threat of serious afterdrop has passed. But this would be minor participation in the treatment after the critical period has passed.

One would expect that most hypothermia victims are recovered before experiencing severely depressed RMV's. For these individuals the *combination therapy* is to be preferred. The exact RMV below which the use of a combination therapy is contraindicated can not be determined from these experiments.

The use of body-to-body heat exchange, which has been widely recommended for use in circumstances where no other treatment is feasible, must be discouraged in treating profound hypothermia. The moderate surface heating would be expected to promote greater afterdrop than might occur if the victim were well insulated from his environment, handled with great care and transported to a facility capable of rendering treatment. With hypothermia known to be mild, body-to-body heat exchange might offer desirable shortening of total rewarming time (by increasing the rate of rewarming) and some subjective improvement in the patient's condition but some additional afterdrop can be expected. If uncertainty exists concerning the severity of the hypothermia, it would be prudent not to risk precipitating an afterdrop that could be dangerous.

An additional problem that exists with body-to-body heat exchange is the potential for it to be applied differently than was done in this research and, in the process, to promote even greater afterdrop than has been indicated here. In this research, body contact was restricted to the upper-body

region of the subject. An over-zealous heat donor might reason that if a little contact is good, then a lot is better. The resulting increase in the surface warming of arms and legs could promote even more afterdrop than results with upper-body contact. This potential for misapplication of body-to-body heat exchange is perhaps the most troubling aspect of even a qualified recommendation for its use.

The question arises, might the body-to-body heat exchange treatment be more effective if it is applied to parts of the patients body other than the back. It could easily be applied to the chest, for example. The thermographs of Hayward, et al. (1973) showed the chest of a normothermic man to radiate more heat than his back. Thus a chest-to-chest arrangement might offer some heat transfer advantage after the recipients chest-surface vasculature had dilated. However, the thermographs show the back and chest of a man who had held still for 15 minutes in cold water to radiate the same amount of heat. Therefore, one would expect no heat transfer advantage during initial rewarming for the chest-to-chest arrangement. It is quite possible that one could accurately regard the heating pads therapy as indicating a limit to performance which may be achieved by improvements to body-to-body heat exchange. The heating pads were placed on the areas thought to maximize heat transfer. In terms of recovery period and rate of rewarming there is abundant potential indicated for refinement of the body-to-body heat exchange approach. However, afterdrops avoidance is the single most important consideration in the treatment of profound hypothermia. The potential for afterdrop avoidance through refinements to body-to-body heat exchange is not indicated, by the results seen with the heating pads, to be attractive.

A final comment on trunk immersion therapy is in order. This therapy has been used only as a standard of comparison for the evaluation of therapies thought to be candidates for use in the field. The assumption has been made that trunk immersion is impractical for such use. There may occur, serious attempts to design special equipment to allow trunk-immersion-like treatment in the rescue environment. If these attempts are successful new questions would warrant answers before the equipment is used. The primary one relates to the physiologic disturbances promulgated by such rapid heating of profoundly-cold patients. The safety of such a treatment for these patients should be established prior to its practical use. Of course, one would expect such treatment of the majority of mild hypothermia cases would be gratefully received by the conscious patients. However, if the rapid rewarming of profound cases were determined to be ill-advised then criteria for determining when it should not be used would need to be developed.

8.0 REFERENCES

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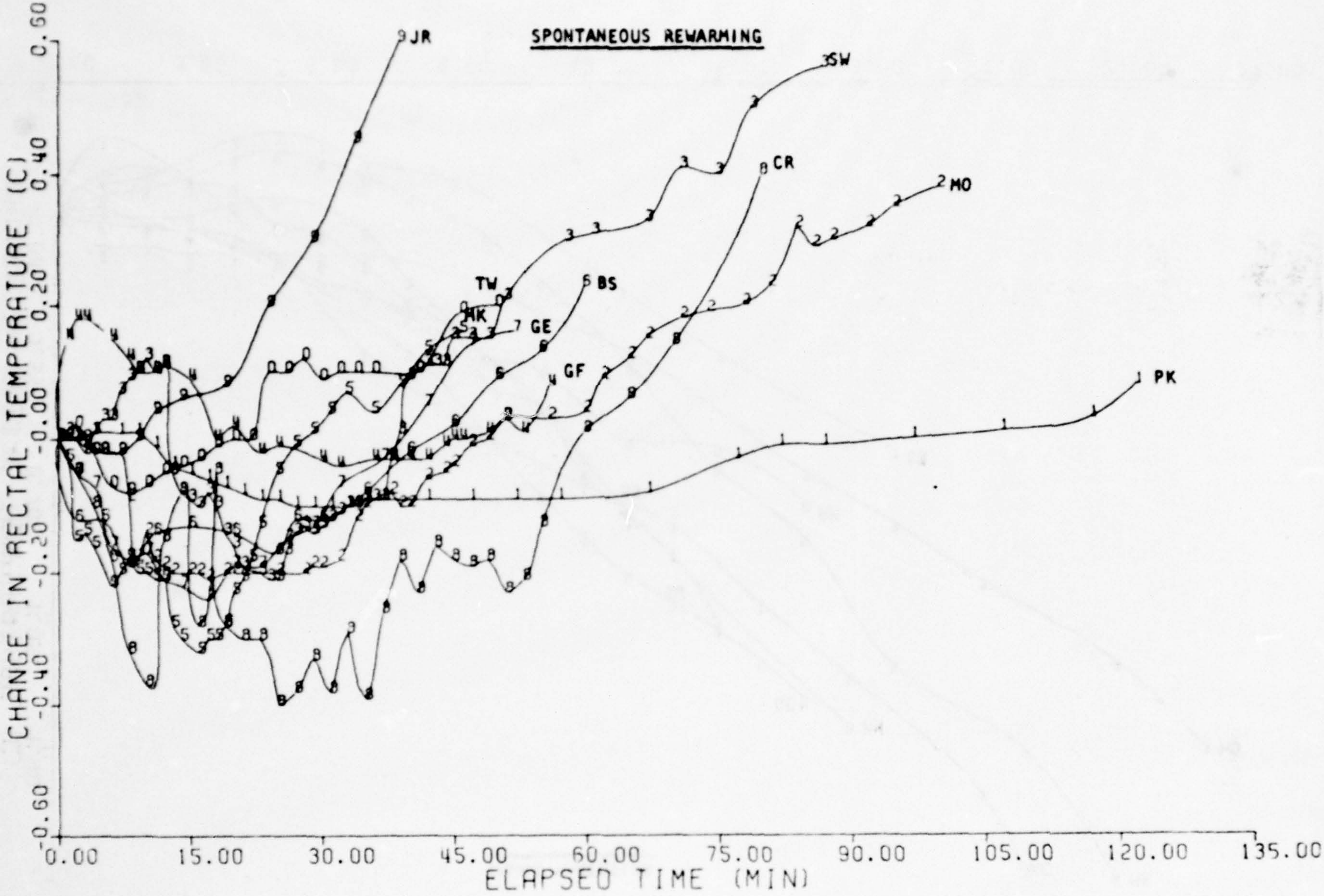
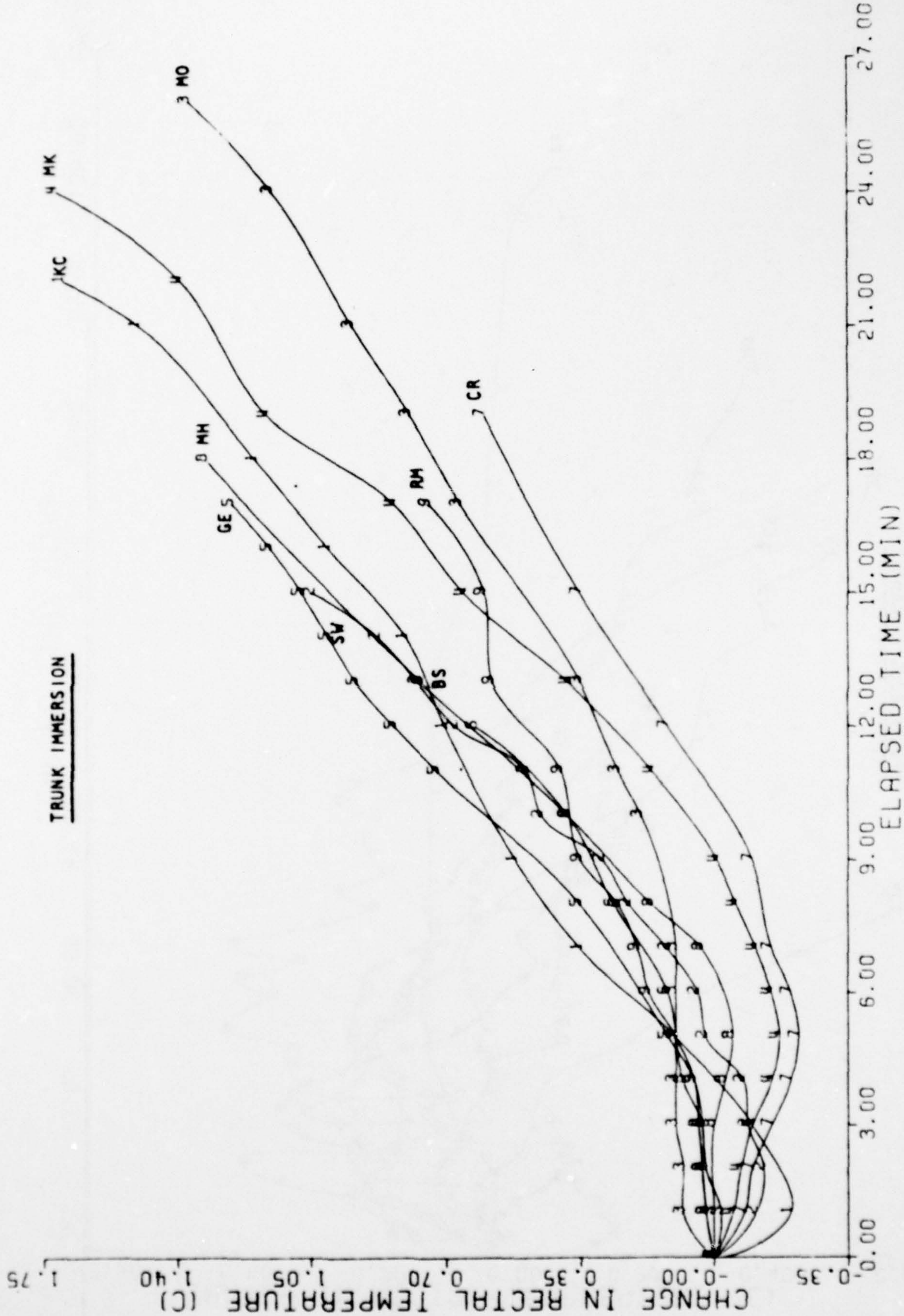
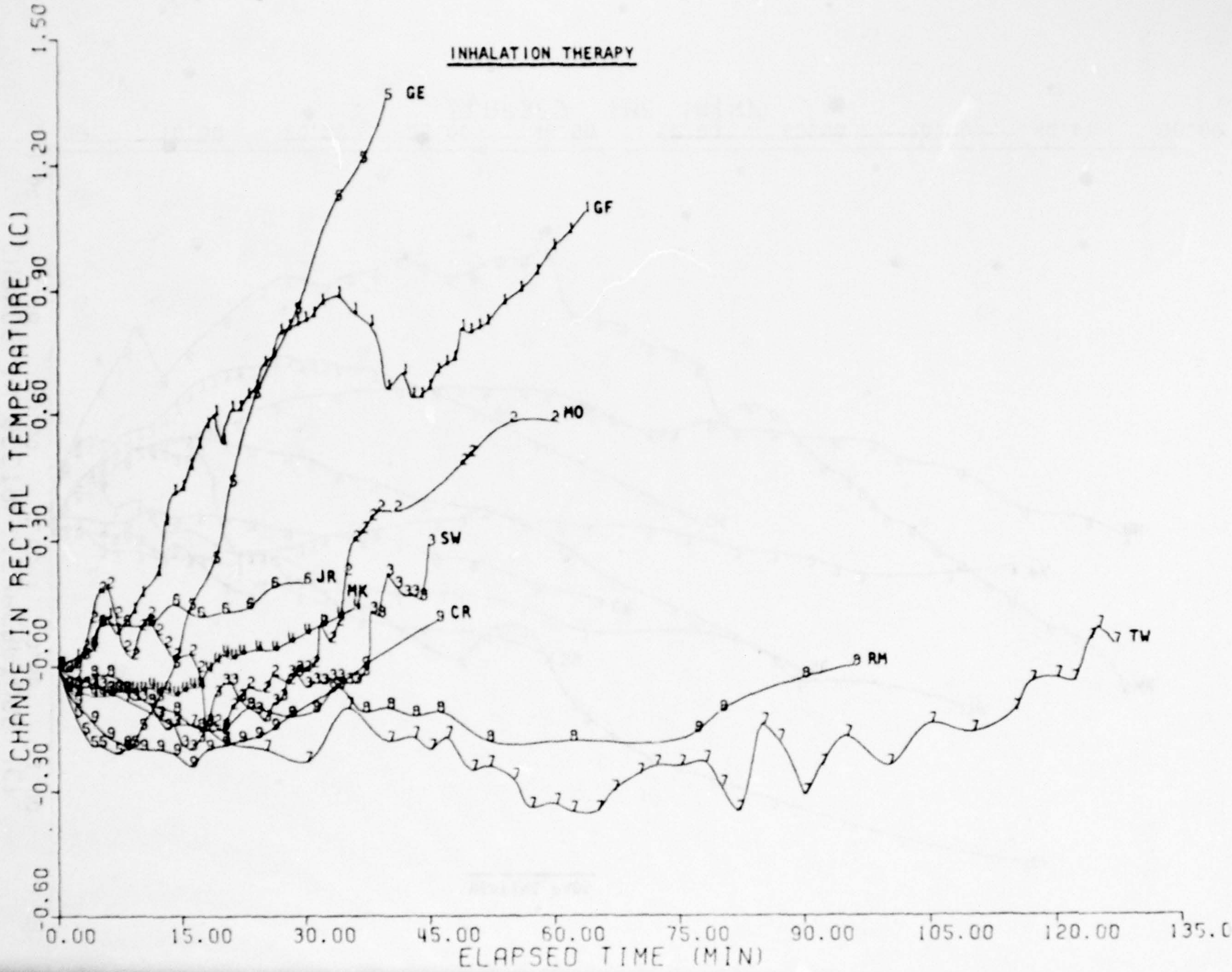
APPENDIX A

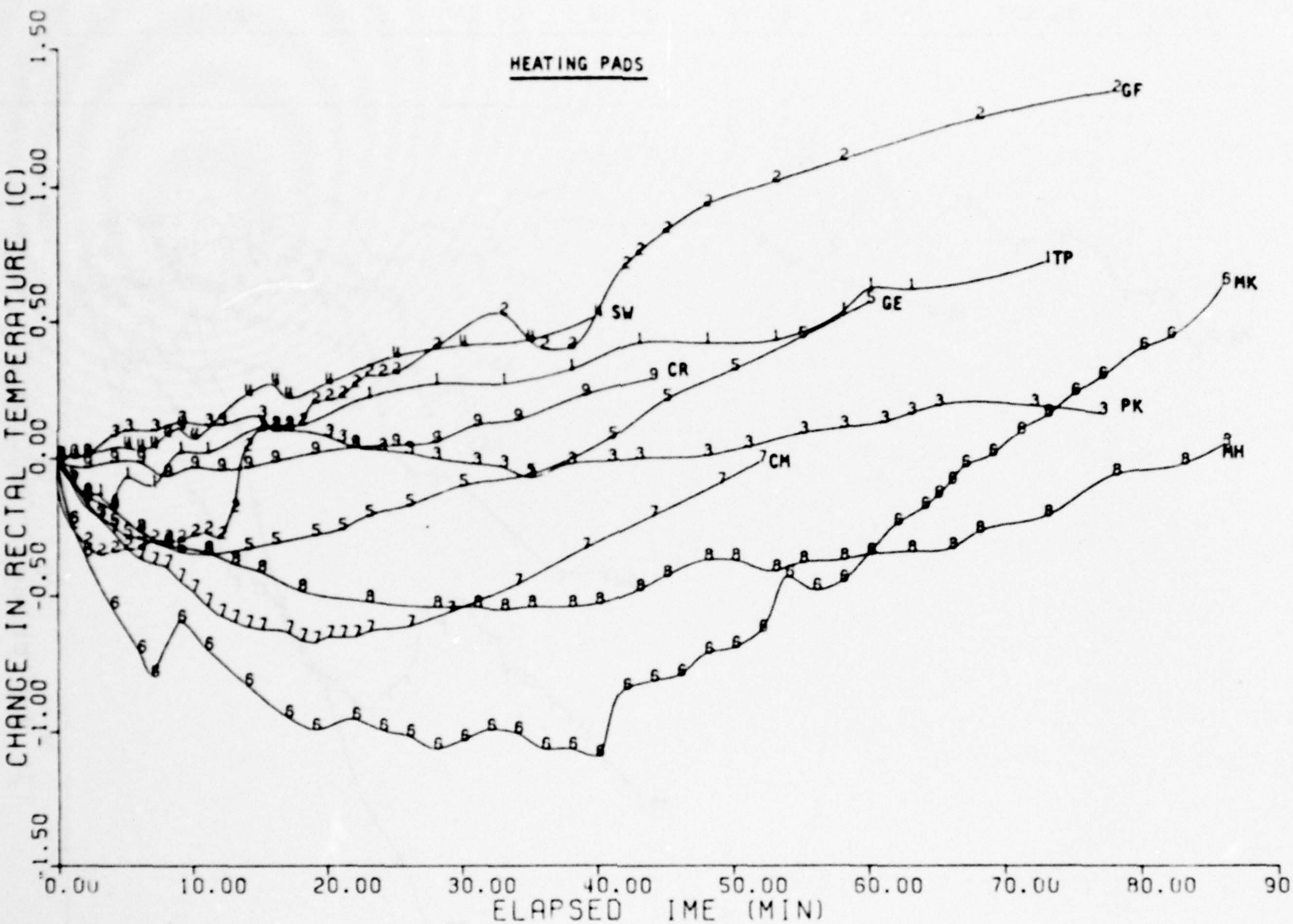
REWARMING TEMPERATURE PROFILES

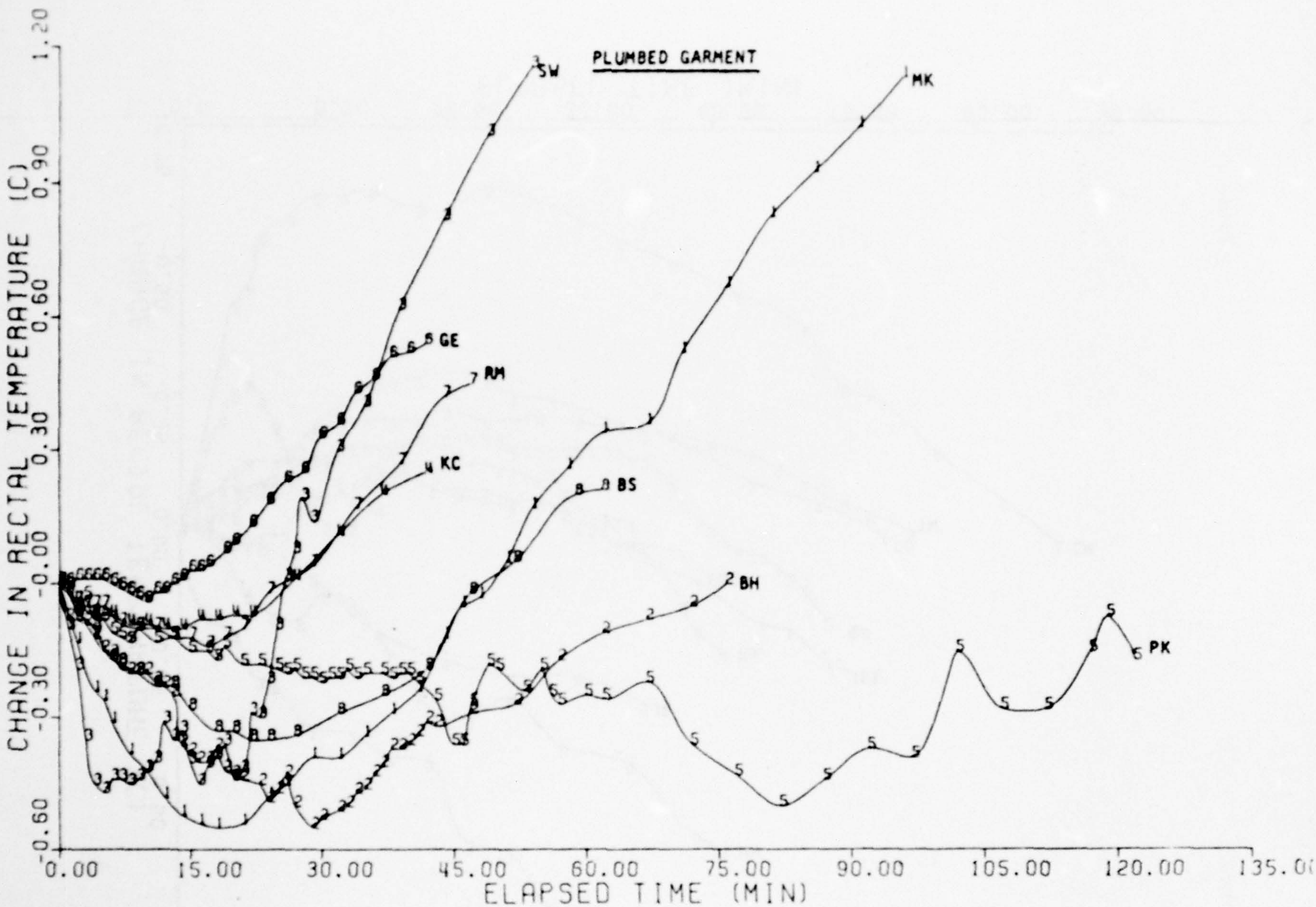

SPONTANEOUS REWARMING
CHANGE IN RECTAL TEMPERATURE (C)
0.60
0.40
0.20
-0.00
-0.20
-0.40
-0.60
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
135.00
ELAPSED TIME (MIN)
JR
SW
CR
MO
TW
HK
GE
BS
GF
PK

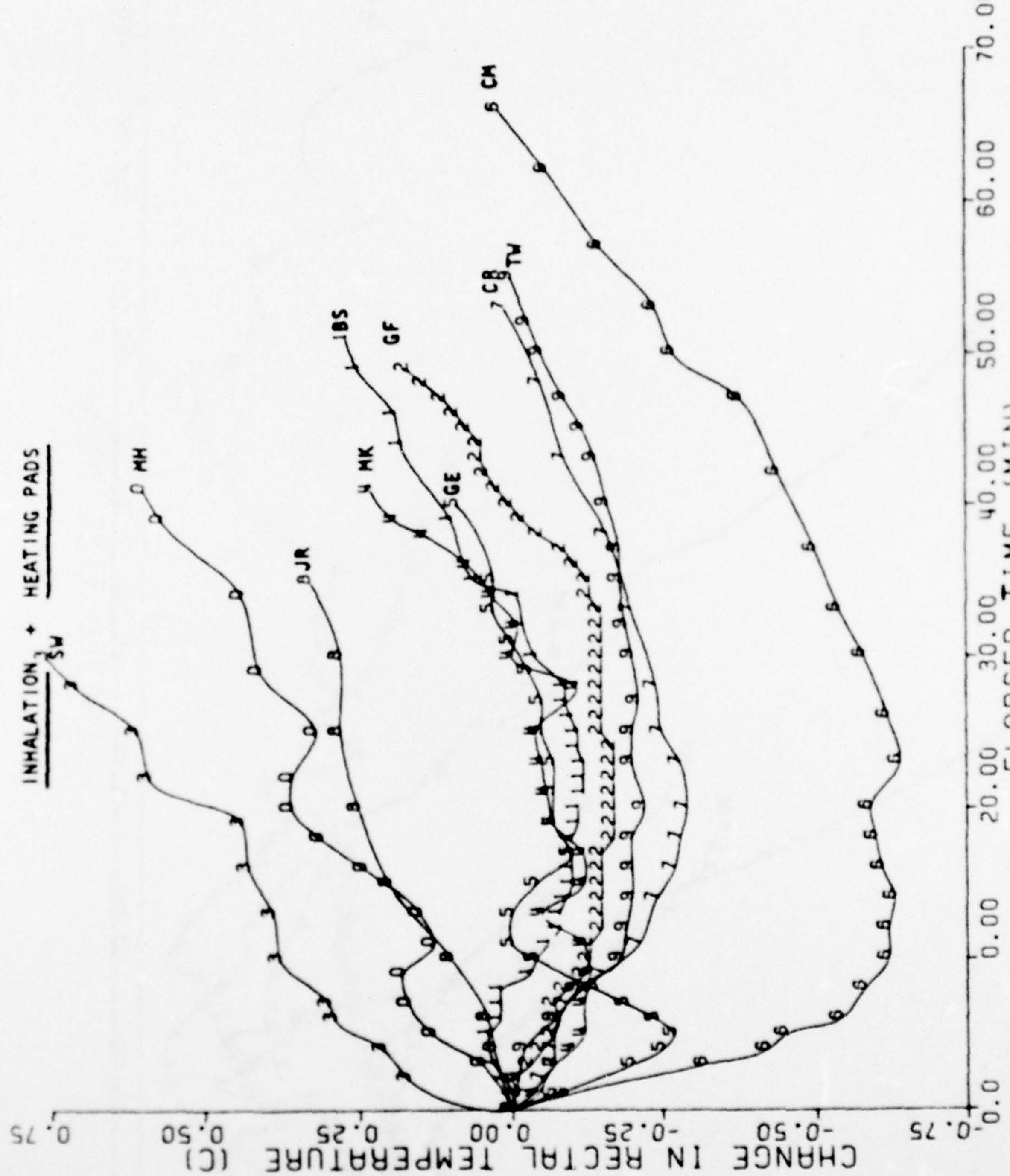


TRUNK IMMERSION
CHANGE IN RECTAL TEMPERATURE (C)
ELAPSED TIME (MIN)
-0.35
-0.00
0.35
0.70
1.05
1.40
1.75
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
1KC
4 MK
3 MO
8 MH
GE 5
9 RM
7 CR
SW
BS

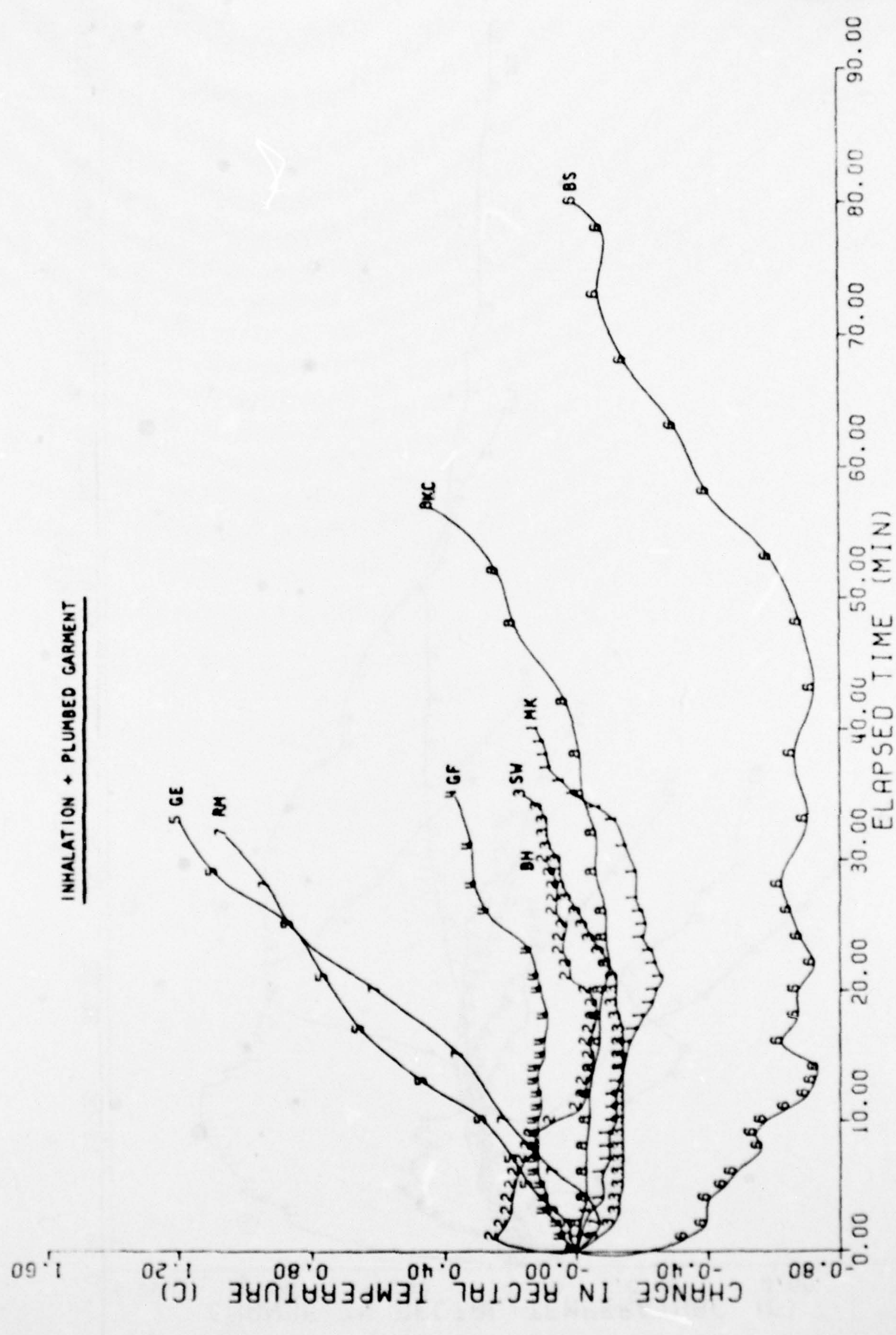

INHALATION THERAPY
GE
GF
MO
SW
JR
MK
CR
RM
TW
CHANGE IN RECTAL TEMPERATURE (C)
1.50
1.20
0.90
0.60
0.30
-0.00
-0.30
-0.60
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
135.0
ELAPSED TIME (MIN)

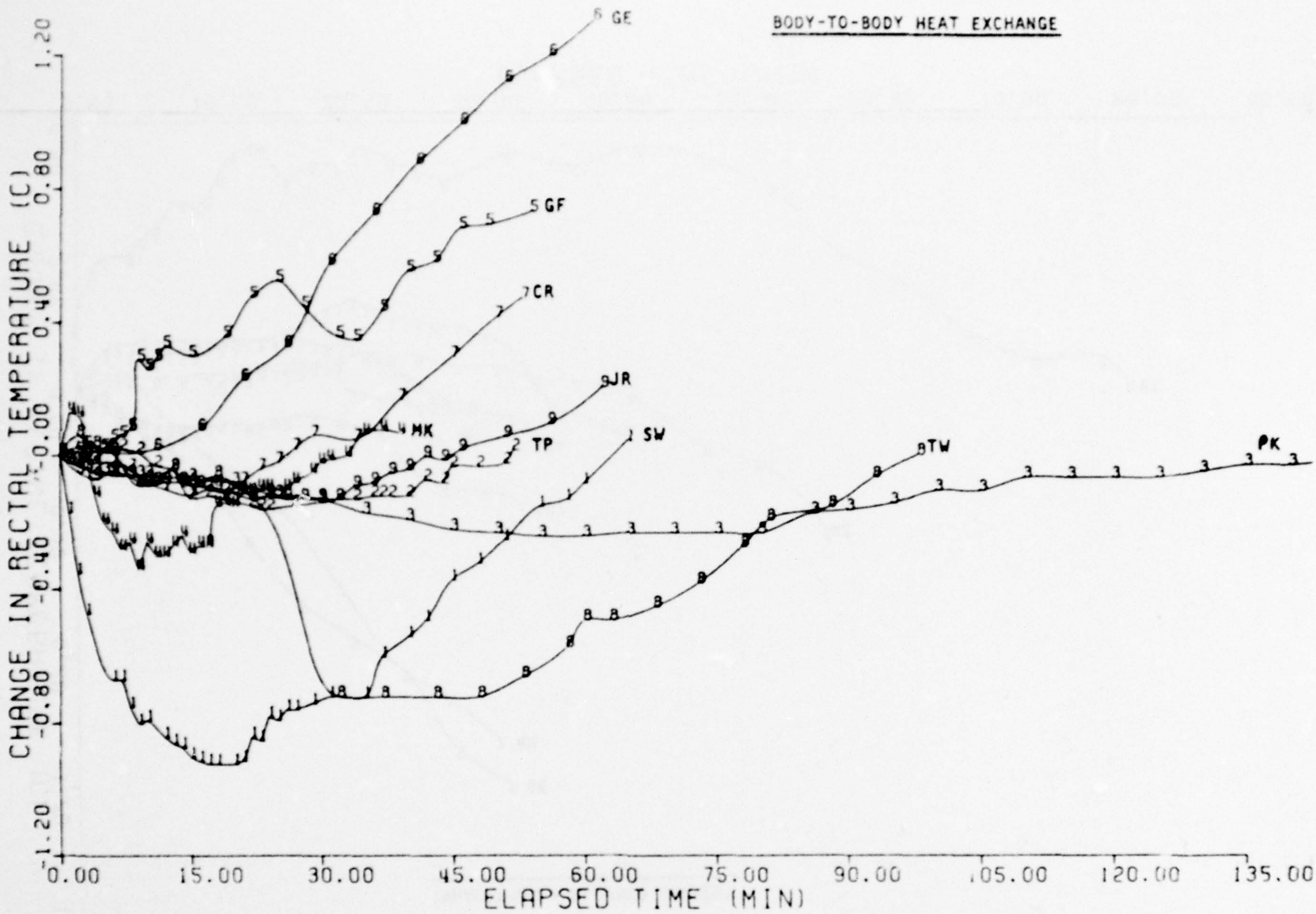

HEATING PADS
CHANGE IN RECTAL TEMPERATURE (C)
ELAPSED IME (MIN)
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
GF
TP
MK
SW
GE
CR
PK
CM
MH


PLUMBED GARMENT
SW
MK
GE
RM
KC
BS
BH
PK
CHANGE IN RECTAL TEMPERATURE (C)
1.20
0.90
0.60
0.30
-0.00
-0.30
-0.60
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
135.00
ELAPSED TIME (MIN)



INHALATION + HEATING PADS
CHANGE IN RECTAL TEMPERATURE (C)
ELAPSED TIME (MIN)
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
0.0
0.00
20.00
30.00
40.00
50.00
60.00
70.00
SW
MH
JR
BS
MK
GF
GE
CB
TW
CM


INHALATION + PLUMBED GARMENT
CHANGE IN RECTAL TEMPERATURE (C)
ELAPSED TIME (MIN)
-0.80
-0.40
-0.00
0.40
0.80
1.20
1.60
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
5 GE
7 RM
4 GF
3 SW
BM
1 MK
8 KC
6 BS


BODY-TO-BODY HEAT EXCHANGE
CHANGE IN RECTAL TEMPERATURE (C)
1.20
0.80
0.40
-0.00
-0.40
-0.80
-1.20
ELAPSED TIME (MIN)
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
135.00
GE
GF
CR
JR
MK
TP
SW
TW
PK